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FINAL REPORT

SPACE STATION COMMUNICATIONS AND TRACKING SYSTEMS MODELING AND RF LINK SIMULATION

PREPARED FOR

NASA LYNDON B. JOHNSON SPACE CENTER

HOUSTON, TX 77058

TECHNICAL MONITOR: MR. DEAN BRATTON

CONTRACT NO. NAS 9-17332

JULY, 1986

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ABSTRACT

In this final report, the effort spent on "Space Station Communications and Tracking System Modeling and RF Link Simulation" is described in detail. The effort is mainly divided into three parts, viz, FDMA system simulation modeling and software implementation, study on "design and evaluation of a functional computerized RF link simulation/analysis system for Space Station", and study on "design and evaluation of simulation system architecture". This report documents the results of these studies. In addition, a separate "User's Manual on Space Communications Simulation System (SCSS), Version 1" documents the software developed for the Space Station FDMA communications system simulation. The final report, SCSS user's manual, and the software located in the NASA JSC system analysis division's VAX 750 computer together serve as the deliverables from LinCom for this project effort.

1. INTRODUCTION

The Space Station communications & tracking (C&T) system to be designed and implemented will be a highly complex system serving various users such as TDRSS, EVA, OMV, OTV, MRMS, SSO, Free-Flyers, and co-orbiting platforms. The system requirements for various users are different. In addition, the whole system is a dynamic system, since some of the users will be moving relative to the Space Station. Thus, accurately evaulating and predicting the C&T system performance could be very complicated, if not impossible, without the help of computer simulation.

The works performed include the functional requirement study of the computer simulation system, design and evaluation of the simulation system architecture, and design and implementation of the simulation system for the FDMA (frequency division multiple access) communications system (SCSS).

In section 2, the SCSS computer package, designed for the FDMA communications system, is described. The FDMA system is simulated since it is the most probable multiple access communications system to be implemented in the Space Station. The FDMA simulation model is described, and some of the typical numerical results are discussed. Currently, the SCSS possesses the capabilities to model the effects of adjacent channel interference, nonlinearities, filtering, and modulation schemes (QPSK, SQPSK). It can be used to study the signal degradation under different kinds of distortions. Graphical signal outputs also allow a user to easily observe the signal processing effect of a system block within the communications link. The numerical results illustrate how a Space Station communications system designer/system engineer can make use of the SCSS to design and analyze the system.

Section 3 discusses the communications system modeling requirements for the Space Station C&T system simulation. The requirements are derived from the general informations documented on NASA JSC's documents on the Space Station. It also addresses the definition of preliminary RF link elements and the associated key parameters. Based on these informations, a description of the building blocks and their key parameters for an end-to-end digital communication link are given. These building blocks and parameters will serve as a requirement guideline for the SCSS Model Library to be fully developed in the next phase of the SCSS development.

Section 4 documents the design and evaluation of simulation system architecture. This simulation system architecture was intended to serve as a tentative guideline for the SCSS. A generic simulation approach was adopted in the study. System block diagrams are given to show the high level overall structure of the simulator. It consists of fourteen system blocks divided into seven subsystems. The functional requirements of each system block are discussed. Whether the generic simulator approach will be adopted for the final SCSS architecture or not, the studies are still very useful in designing the overall simulator architecture.

2. FDMA SYSTEM SIMULATION (SCSS)

2.1 Introduction

Since the Space Station has to communicate simultaneously to many users in different locations, a multiple access (MA) communications system has to be available. Among the many choices of the multiple access system, the frequency division multiple access (FDMA) system is most likely the candidate to serve for this purpose.

The multiple access system will be required to handle users at the distance ranging from vicinity to 2000 km. The data rate may vary from 128 KBPS to 22 MBPS. Totol number of users may be about 20 in the growth stage. Due to the wide dynamic range of the signal level, consideration will be given to the power control of each channel, so that adjacent channel interference (ACI) will not be too severe to the system performance. The frequency spectrum available to the Space Station MA system is limited, and therefore spectrum allocation to each channel has to be carefully planned. In addition, it is also coupled with the ACI effect. Thus the channel frequency separation is an important parameter to be decided.

Since the FDMA system to be considered is a highly complex and evolving system, exact system performance will be very difficult, if not impossible, by using analysis alone. On the other hand, Monte-Carlo types of simulation [1] will be either too slow or difficult to implement. It is the intention to use the analytic simulation approach [2], which combines together the analysis and simulation, to perform the design and analysis of this MA system. The computer package developed for this purpose, Space Station Communication Systems Simulator (SCSS), satisfies both the requirements of speed and flexibility.

In section 2.2, the FDMA model is discussed. The SCSS output format is illustrated in section 2.3. Section 2.4 shows the performance sensitivity to some of the system parameters. Design and analysis of the Space Station FDMA system are discussed in section 2.5.

2.2. FDMA Model

The FDMA end-to-end communications system to be modeled in SCSS is shown in Fig. 2.1, with the system parameters of each block to be modeled shown below the corresponding block. The system models the QPSK/SQPSK modulation schemes with or without convolutional code (constraint length 7, rate 1/2). An NRZ baseband format is assumed. The baseband signal used models a 3.5% of symbol duration rise time, measured from 5% to 95% of the peak amplitude, as depicted in Fig. 2.2.

2.2.1 Pulse Shaping Filter

The pulse shaping filter is assumed to be a raised-cosine filter. The amplitude response of the filter is given by

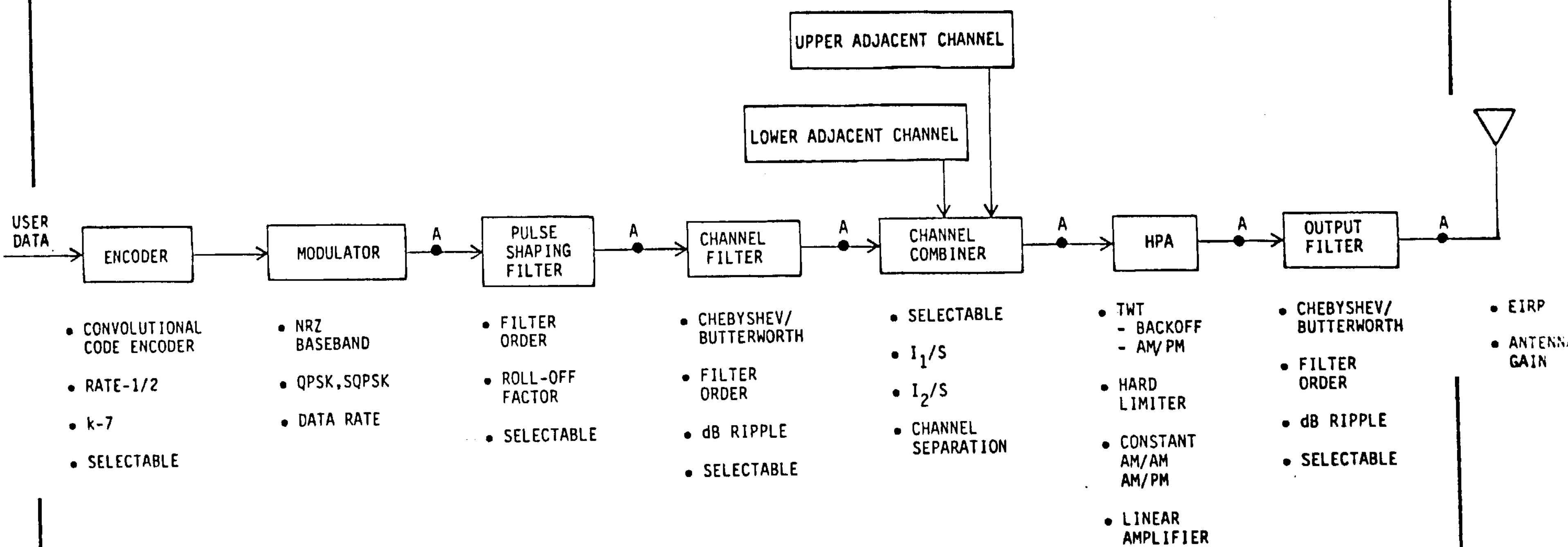

Figure 2.1a FDMA System Transmitter Model.

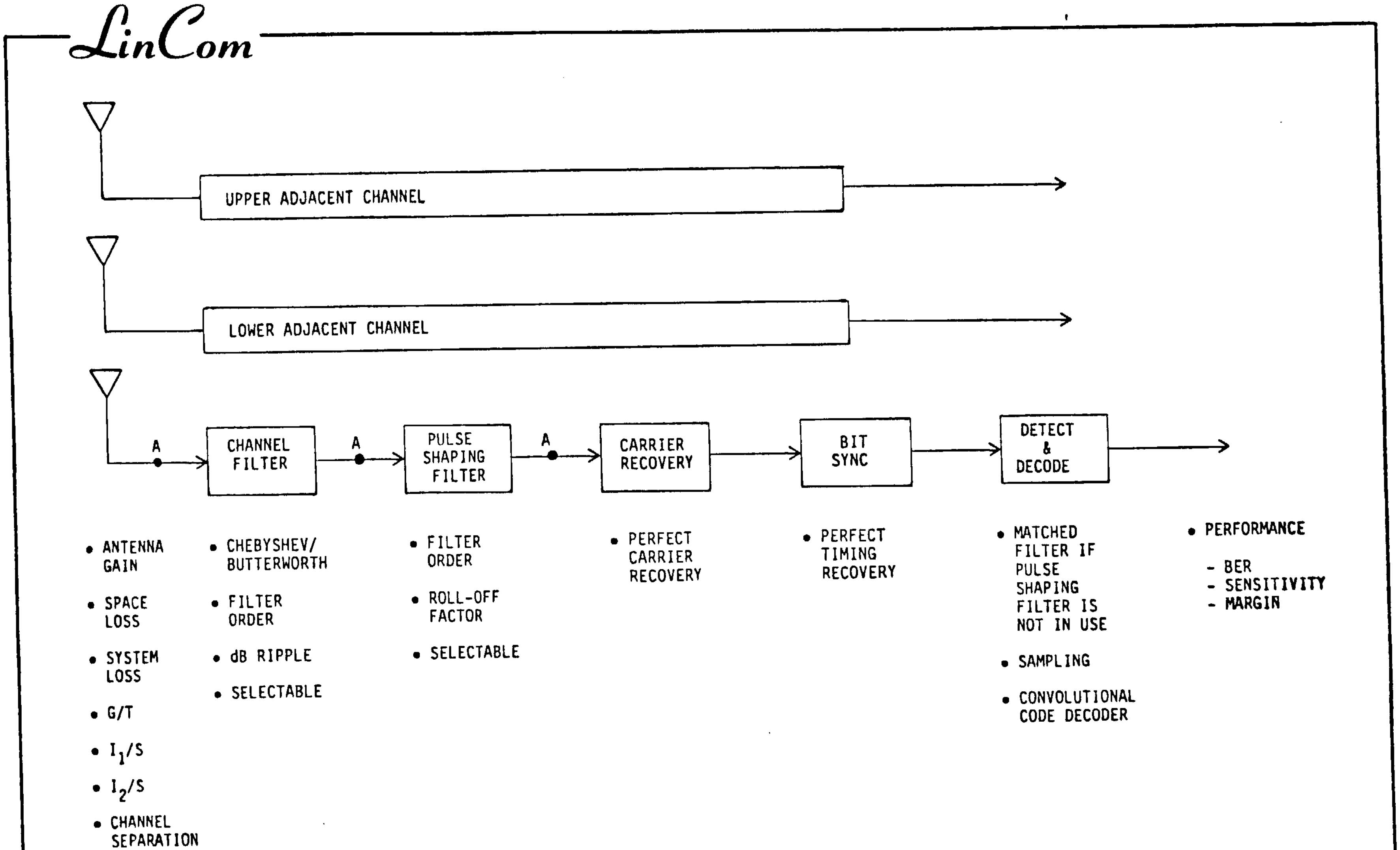

Figure 2.1b FDMA System Receiver Model.

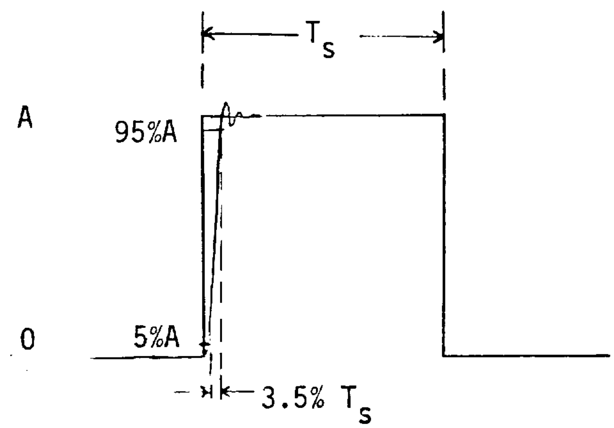

Figure 2.2 Rise-Time Modeling in NRZ Baseband Signal.

$$|H(j\omega)| = \begin{cases} 1 & 0 \le \omega \le \frac{\pi}{T_s}(1-\alpha) \\ \cos^2\left\{\frac{T_s}{4\alpha}\left[\omega - \frac{\pi(1-\alpha)}{T_s}\right]\right\} & \frac{\pi}{T_s}(1-\alpha) \le \omega \le \frac{\pi}{T_s}(1+\alpha) \\ 0 & \omega > \frac{\pi}{T_s}(1+\alpha) \end{cases} \tag{1}$$

where $\omega = 2\pi f$, and α is the filter roll-off factor. An option is provided to put a full raised-cosine filter in the transmitter or receiver. It is also allowed to equally split the filter between the transmitter and the receiver. It has been shown [3] that under a linear bandlimited channel assumption the equally split configuration (i.e., the filter in the transmitter and receiver are identical, and the cascaded transfer function takes the form of a raised-cosine filter transfer function) is optimal since it satisfies both the Nyquist and the matched filtering criteria. In case raised-cosine filters are used, a x/sin(x)-shaped amplitude equalizer is added to the channel also.

2.2.2 Channel Filter

The channel filter models the channel characteristics. A Butterworth or a Chebyshev filter of selectable filter order and ripple (in the case Chebyshev filter is used) can be selected. The bandwidth of the channel filter is one of the major system parameters to be determined. The bandwidths of all the filters are defined to be one-sided RF or equivalently two-sided baseband bandwidth. The Chebyshev filter characteristic along with the bandwidth definition is illustrated in Fig. 2.3.

2.2.3 Adjacent Channel Interference

The SCSS currently models two adjacent (upper and lower frequency) channels along with the desired signal channel. It is assumed that all three channels possess the same baseband signal characteristics (data rate and modulation format) except the signal power and data pattern. The user can select the ACI power by specifying the interference-to-signal power ratios, I1/S and I2/S. The data patterns and phases are selected so that the three channels possess the least cross correlations. The ACI can enter into the simulation model at either one of the two different locations, namely, the channel combiner in the transmitter and the receiver antenna. For the former case, all the three channels go through the same high power amplifier (HPA), while for the latter case, each channel has its own HPA. This option allows one to trade the number of HPAs required against signal degradation.

2.2.4 HPA

The HPA models four different types of amplifiers, viz., linear amplifier, hard-limiter, TWTA, and constant AM/AM and AM/PM characteristics.

2.2.4.1 Linear Amplifier

The linear amplifier has a constant arbitrary gain and no

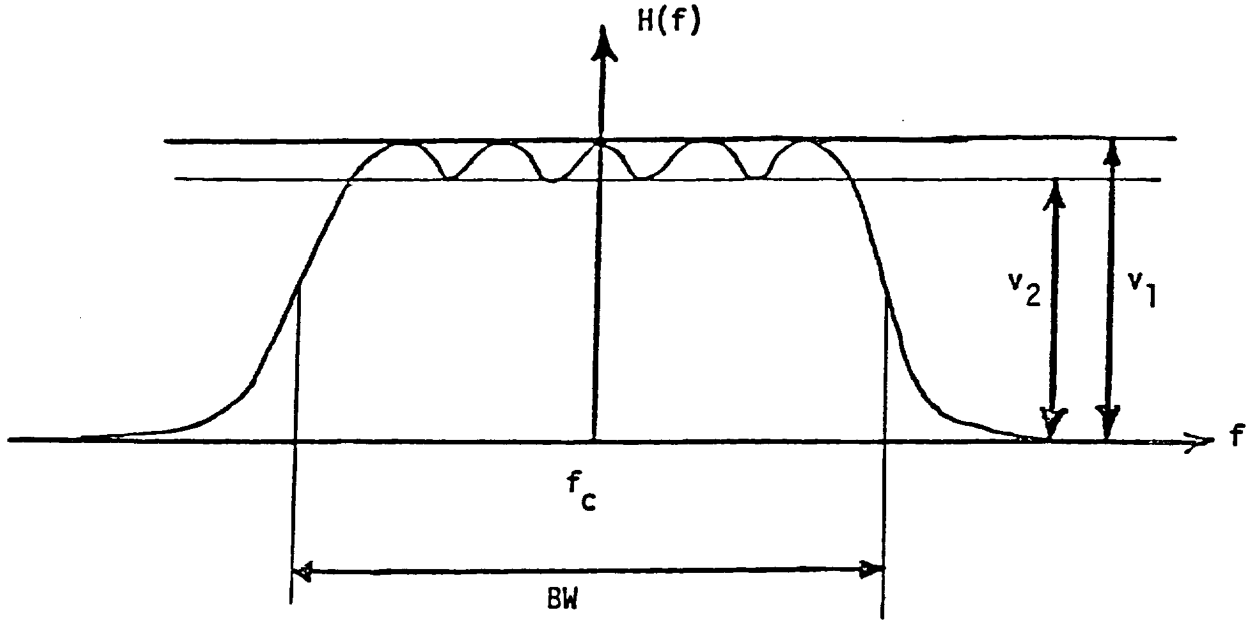

Figure 2.3 Chebyshev Filter Characteristic.

phase shift. The input power is automatically adjusted so that the output power agrees with the specified amplifier output power, viz., the output saturation power (dBW) minus the output backoff (dB). It is understood that the terms "output saturation power" and "output backoff" are meaningless for a linear amplifier; however, they are used in the above definition of output power in order to reach a closer agreement with the TWT amplifier operating point definition.

2.2.4.2 Hard Limiter

The hard limiter will return a constant envelope signal given a signal input. The phase of the input signal remains unchanged.

2.2.4.3 TWTA

The TWTA models the Hughes 261H tube [4] and is shown in Fig. 2.4a. The AM/PM characteristic in the TWTA is defined as

$$\text{AM-PM} = \frac{dg(R)}{d[20\log_{10}R]} = \frac{\ln(10)}{20}\,\frac{R\,dg(R)}{dR}\left[\frac{\text{deg}}{\text{dB}}\right] \qquad (2)$$

The normalized AM/PM function is plotted in Fig. 2.4b. It peaks at approximately 8.2 dB input backoff, which in turns means that the worst degradation due to AM/PM can be expected if the TWTA input signal power is 8.2 dB below the saturation power.

2.2.4.4 Constant AM/AM, AM/PM Characteristics

The AM/AM distortion is defined as

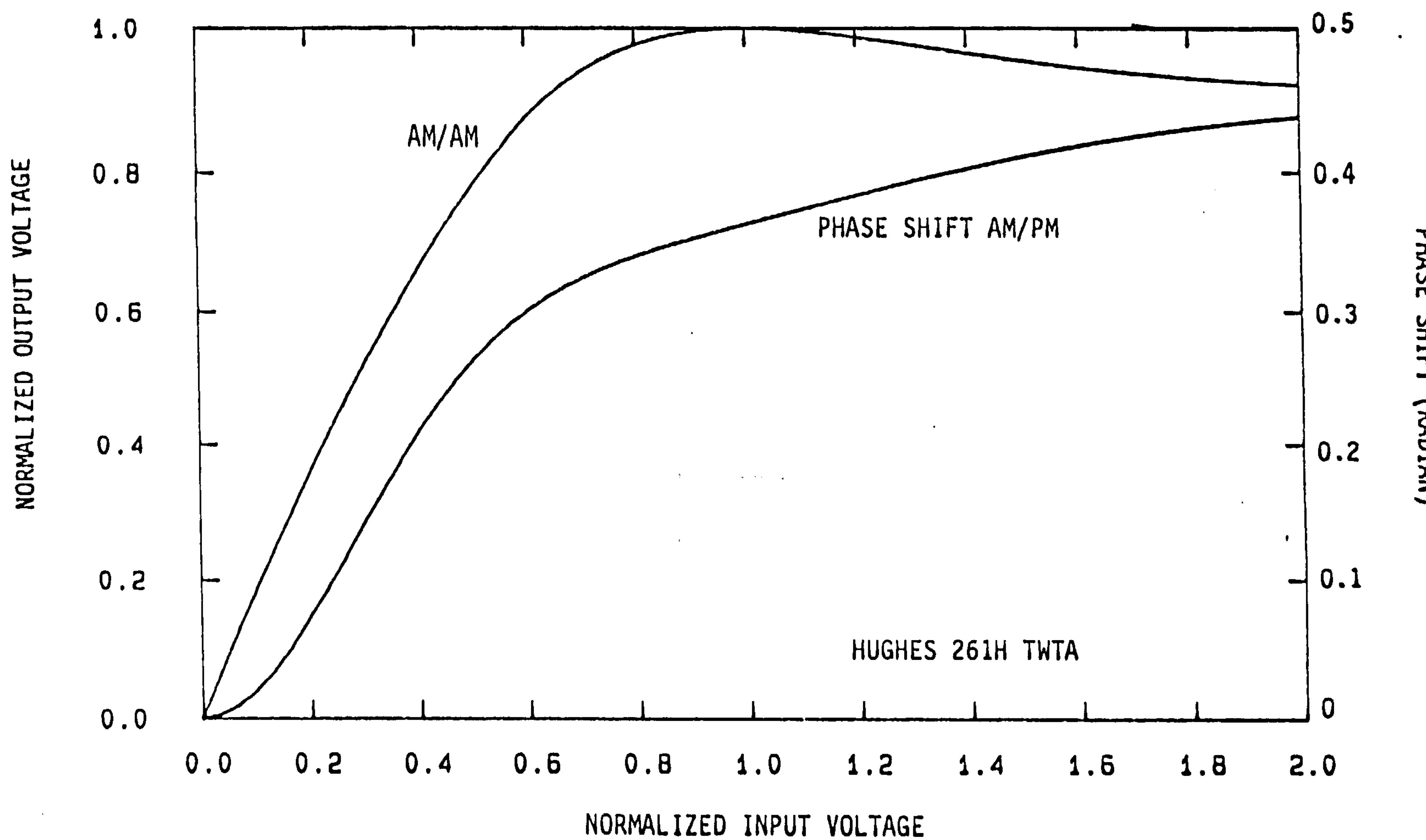

Figure 2.4a Normalized TWT AM-AM Characteristics.

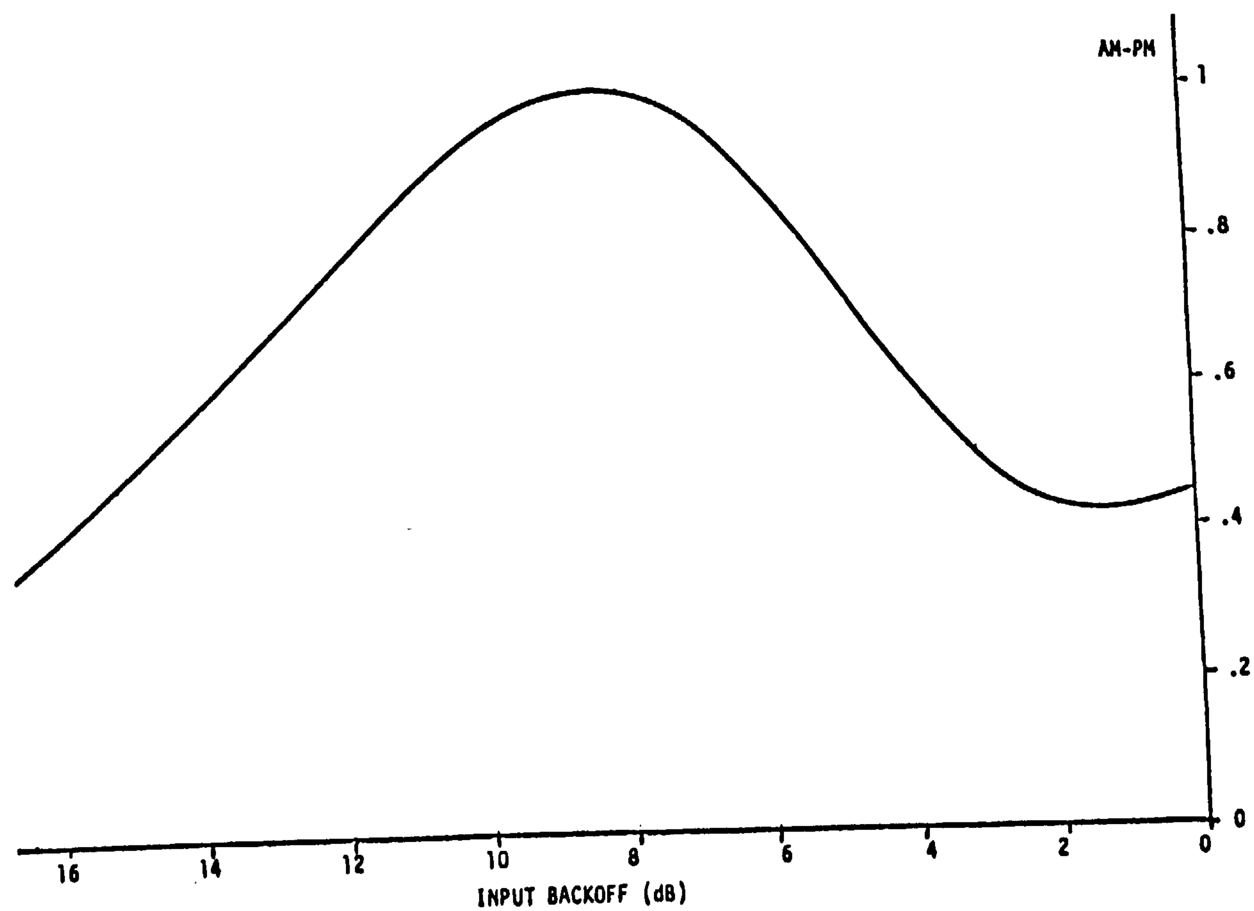

Figure 2.4b Normalized TWT AM-PM Characteristic.

$$AM\text{-}AM = \frac{d[20 \log_{10} f(R)]}{d[20 \log_{10} R]} = \frac{R}{f(R)} \frac{df(R)}{dR} \left[\frac{dB}{dB}\right] \tag{3}$$

and the AM/PM distortion is given in (2). If AM/AM and AM/PM are constants, then we obtain over all operating points

$$f(R) = R^{AM\text{-}AM} \tag{4}$$

$$g(R) = \begin{cases} AM\text{-}PM\ 20 \log_{10} R & R > \varepsilon \\ AM\text{-}PM\ 20 \log_{10} \varepsilon & R < \varepsilon \end{cases} \tag{5}$$

where ε is some small (with respect to r.m.s. signal) number. As in the case of the linear amplifier the terms "output saturation power" and "output backoff" are not applicable to this characteristic. They are however used to define the output power in the same way as for the linear amplifier.

2.2.5 Output Filter

The output filter is modeled as a Chebyshev or Butterworth filter as described for channel filters. It is used mainly to suppress the high frequency components generated by the nonlinearity.

2.2.6 Receiver Channel Filter

The receive antenna for the intended user receives both the signal and adjacent channel interferences. The receiver channel filter, similar to the one in the transmitter, is used to extract the signals which fall within the signal channel bandwidth.

2.2.7 Receiver Pulse Shaping Filter

The structure of the receiver pulse shaping filter is determined by the transmitter pulse shaping filter, if one is to be used. Generally, an equally split raised-cosine filter is used. In the case a matched filter is desirable, Nyquist filter will not be selected.

2.2.8 Carrier and Bit Synchronizers

The carrier and bit synchronizers are assumed to be idealized carrier and timing recovery circuits. The signal input to the signal detector will be synchronized to the best phase and timing so that the minimum symbol error rate can be achieved.

2.2.9 Detector and Decoder

The detector provides the symbol error rate for coded data. Otherwise, bit error rate will be given. The decoder yields the bit error rate if convolutional coding is chosen. It relates the input symbol error rate and the output bit error rate.

2.3 SCSS Output Format

One of the design goals of the SCSS is to provide the user an analysis tool to support communications system design. In order to achieve that, signal information along the whole communications link will be generated as an option. These informations are displayed in graphical forms including time domain waveforms, power spectrum, phasor diagram, eye diagram, signal trace diagram, and BER curve. Both intermediate and final results are available to the user to simplify link analysis. The "observation points" where intermediate results can be obtained are marked by the symbol "A" along the link in Fig. 2.1.

Fig. 2.5 is a typical time domain waveform diagram with two signals displayed simultaneously. With this capability, two different signals along the link can be compared. Fig. 2.6 is a typical power spectrum. Here the spectrum contains both the desired signal and the ACI. The level of the ACI in the frequency domain can be observed. Typical displays of an eye diagram, a phasor diagram, and a signal trace diagram are shown in Figs. 2.7, 2.8, and 2.9 respectively. The diagrams shown in Figs. 2.5, 2.7, and 2.8 are phase corrected, i.e., with the carrier phase offset first removed. The signal trace diagram in Fig. 2.9 displays the signal samples of both the I and Q channels at the same time. In order to see the real signal samples (including the phase introduced into the signal) the signal is displayed without phase correction.

The SCSS is able to interface with a Dynamics Simulation System (DSS) which provides all the communications parameters due

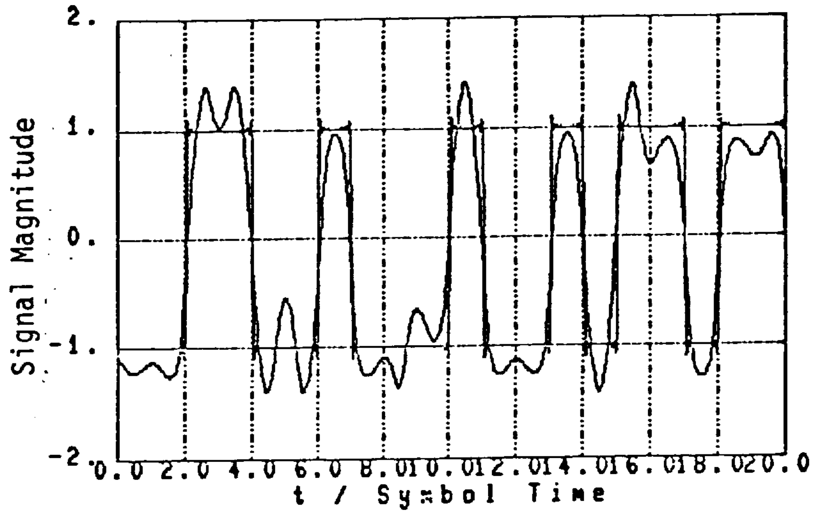

Figure 2.5 Typical Signal Waveform.

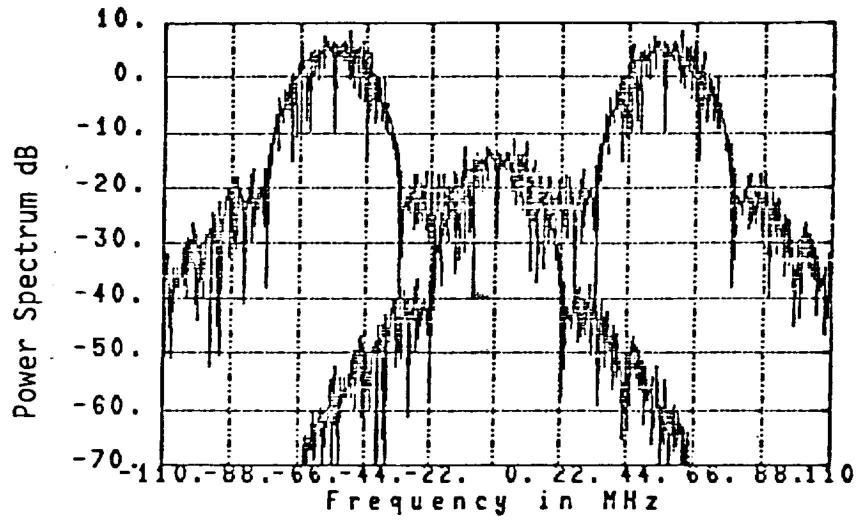

Figure 2.6 Typical Signal Plus ACI Power Spectrum.

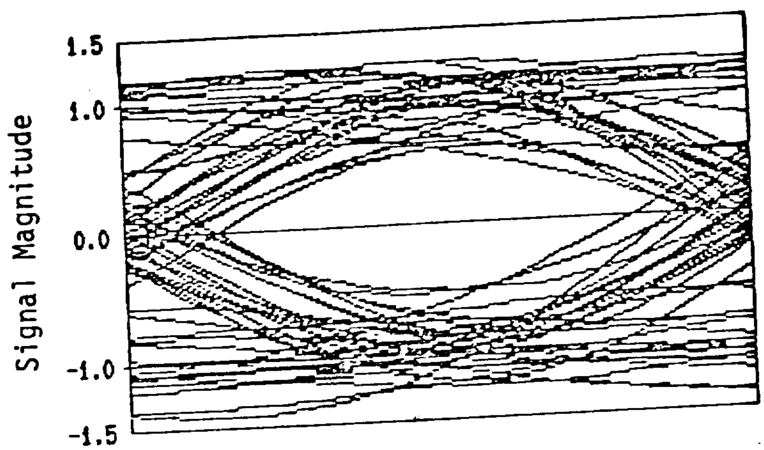

Figure 2.7 Typical Eye Diagram.

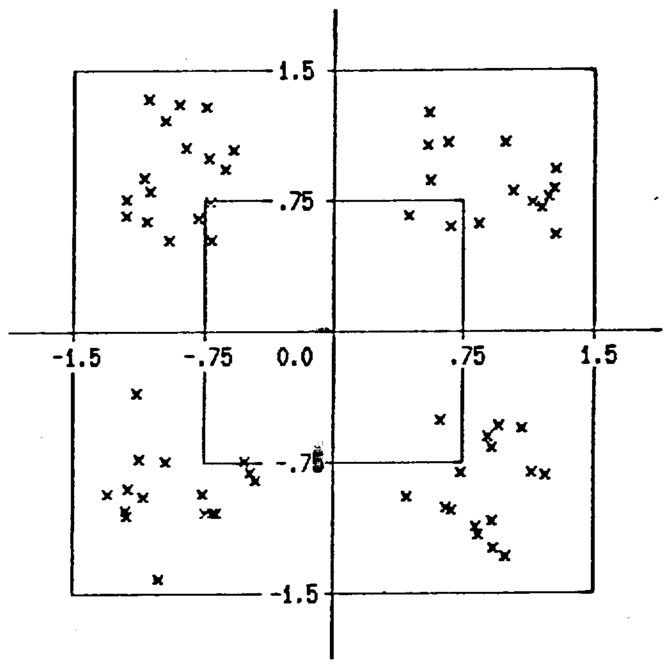

Figure 2.8 Typical Phasor Diagram.

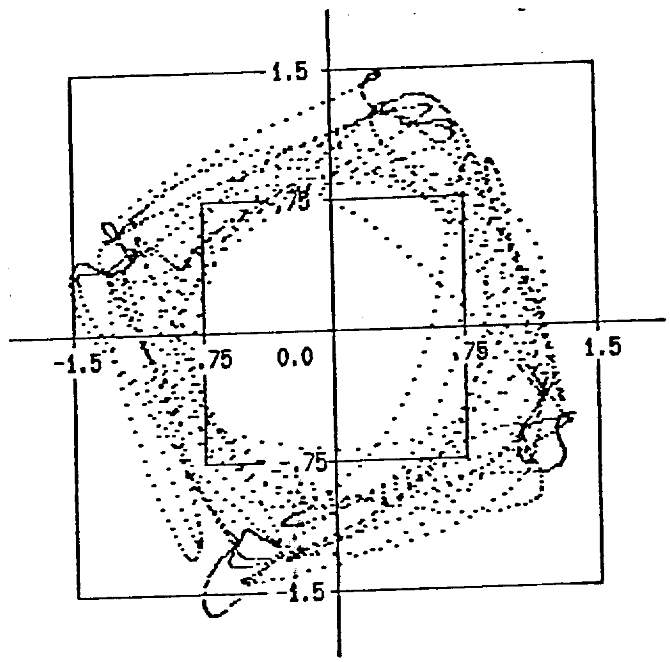

Figure 2.9 Typical Signal Trace Diagram.

to system dynamics. Time-line system performance can thus be evaluated by the SCSS. With the help of this interface, system specification can be obtained for all system dynamics. Details of using SCSS along with DSS is discussed in the SCSS User's Manual.

2.4 System Parameter Sensitivities

In this section, SCSS numerical results of the FDMA communications system for the Space Station scenario are presented. Design and analysis based on these results will be discussed in the next section. The default parameters used in the SCSS analytic simulation are given in Table 2.1. These parameters are used unless otherwise explicitly specified. System performance are given in terms of signal degradation in dB relative to the ideal wideband linear additive white Gaussian noise channel without interference.

Fig. 2.10 shows the performance of QPSK and SQPSK as a function of channel separation. Comparing to QPSK, the SQPSK has a less signal degradation since it possesses lower sidelobes after the nonlinearity.

Fig. 2.11 compares the system performance as a result of using a single composite HPA versus three individual HPAs. It is shown that for all channel separation of interest passing three channels through a single HPA may be about 3 dB worse than using three HPAs for three channels.

The effects of ACI on system performance are demonstrated in

Table 2.1 SCSS FDMA Default Parameters

Data Rate	22 MBPS
Modulation	SQPSK
Coding	Convolutional Code (7,1/2)
Tx Pulse Shaping Filter	Half Raised-Cosine Roll-Off Factor 90%
Tx Channel Filter	Chebyshev Filter, 7th Order, 0.1 dB Ripple, BW=45 MHz
HPA	Hughes 261H TWT, 0 dB Output Backoff
Tx Output Filter	Not Used
Adjacent Channel Interference	Channel Separation, 55 MHz I1/S = I2/S = 20 dB Each Channel Has Own HPA
Rx Channel Filter	Chebyshev Filter, 7th Order, 0.1 dB Ripple, BW=45 MHz
Rx Pulse Shaping Filter	Half Raised-Cosine Roll-Off Factor 90%

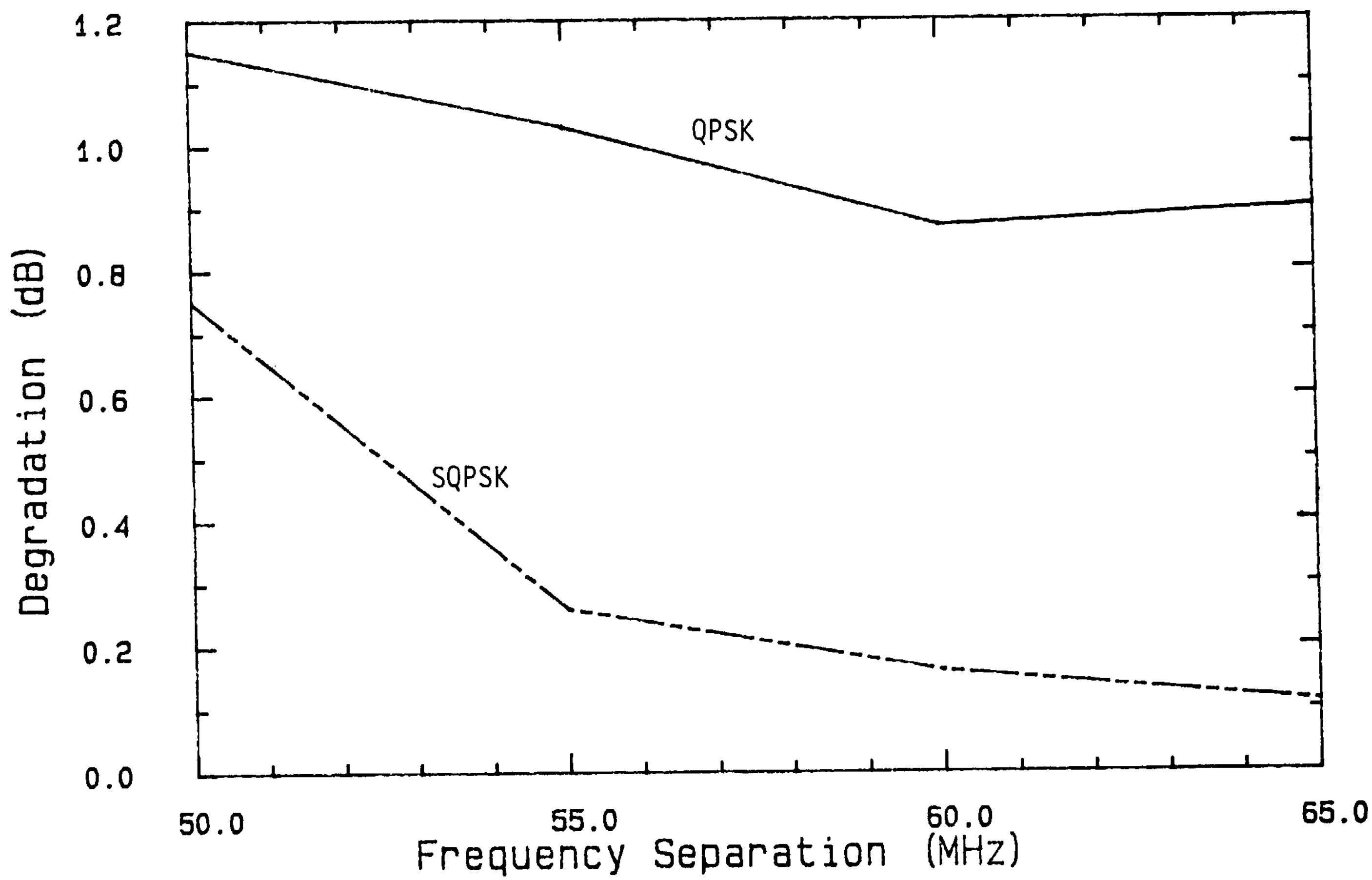

Figure 2.10 Performance Comparison of QPSK and SQPSK.

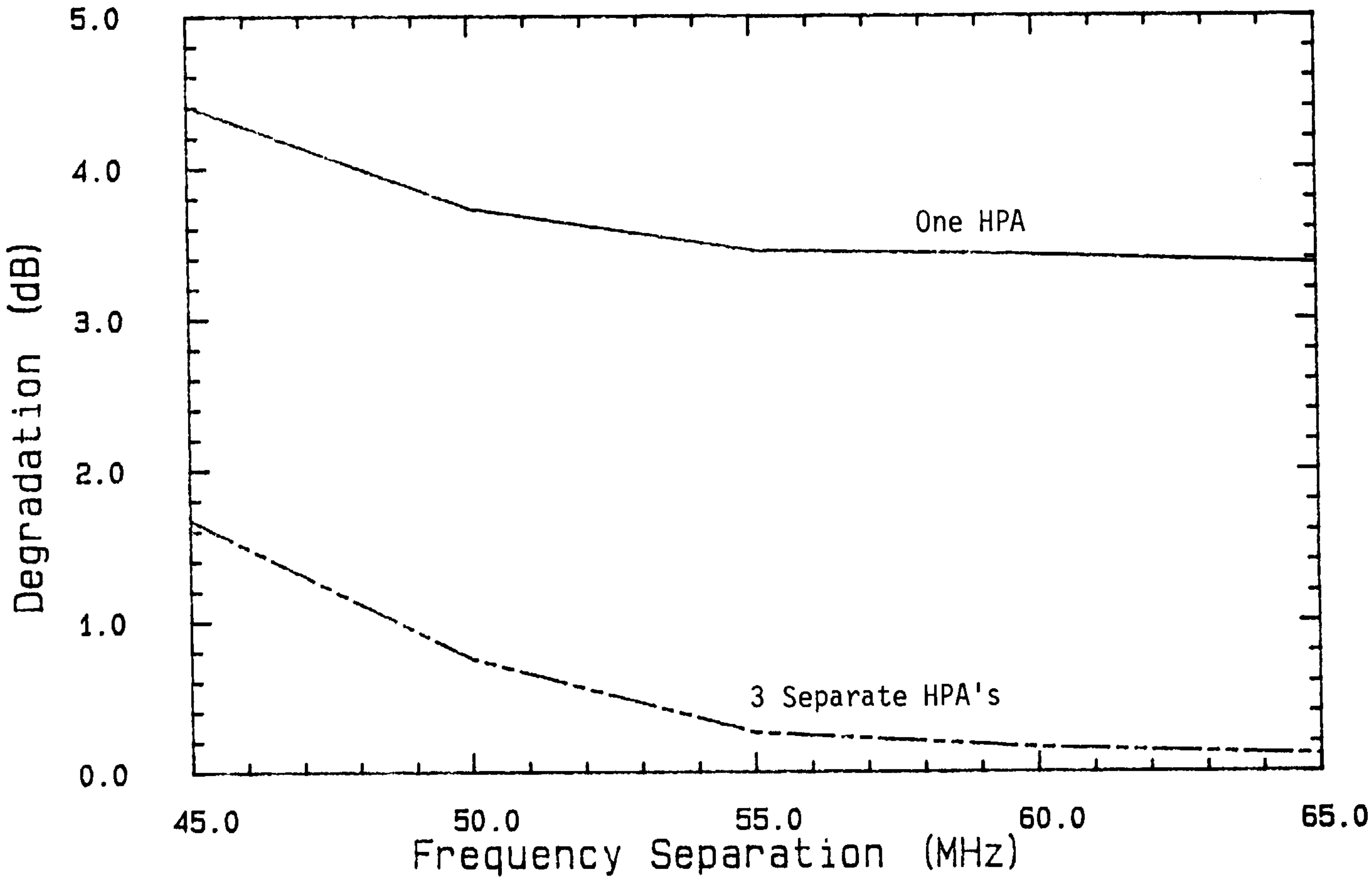

Figure 2.11 Performance Comparison Between Using One and Three HPA's.

Fig. 2.12. For interference-to-signal power (I1/S=I2/S) equal to 20 dB or less, degradation will be within 1 dB if the channel separation is greater than about 49 MHz. They more or less converge when channel separation is greater than 60 MHz. For the case of I/S=30 dB, degradation is about 0.6 dB more at 60 MHz.

Fig. 2.13 shows the effect of the roll-off factor of the transmitter and receiver pulse shaping raised-cosine filters. In the presence of nonlinearity and ACI, an optimal roll-off factor can be found to obtain the minimum signal degradation. The optimal roll-off factor for I1/S=I2/S=30, 20, and 10 dB are respectively about 57%, 90%, and 100%.

The effect of the channel filter bandwidth on system performance is shown in Fig. 2.14. For frequency separation greater than about 51 MHz, a larger filter bandwidth gives better performance (in the presence of ACI). However, for frequency separation less than about 49 MHz, the filter with bandwidth equal to 25 MHz yields better performance comparing to 35 and 45 MHz bandwidth. It is so because in this region the ACI effect dominates, and a smaller filter bandwidth helps to eliminate the adjacent channel interference.

2.5 Design & Analysis

Based on the SCSS results in Section 2.4, a FDMA system in the Space Station environment can be designed. It is clear that SQPSK is a better candidate compared with QPSK in this environment. The use of raised-cosine pulse shaping filter also

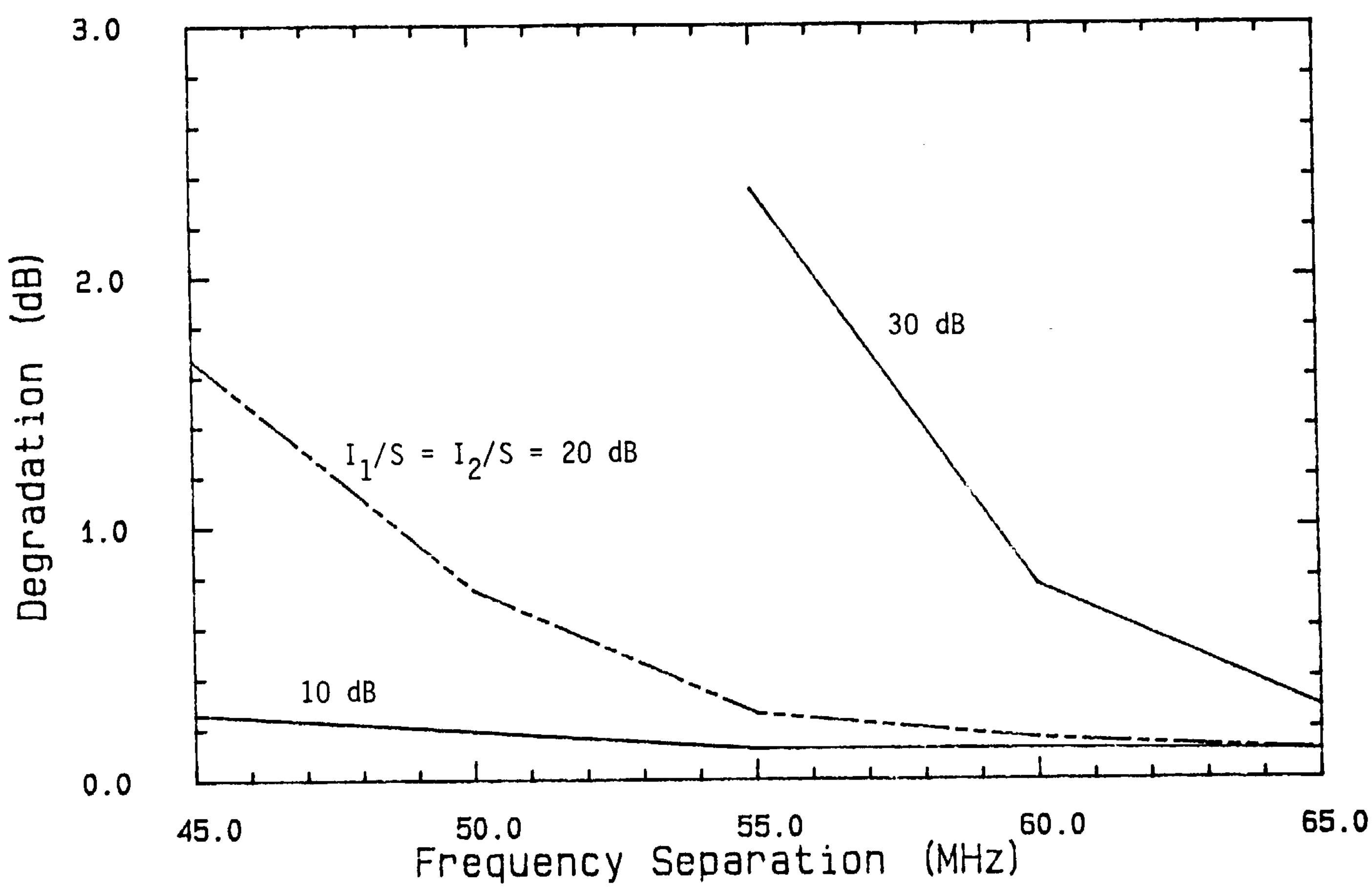

Figure 2.12 Performance as a Function of I/S.

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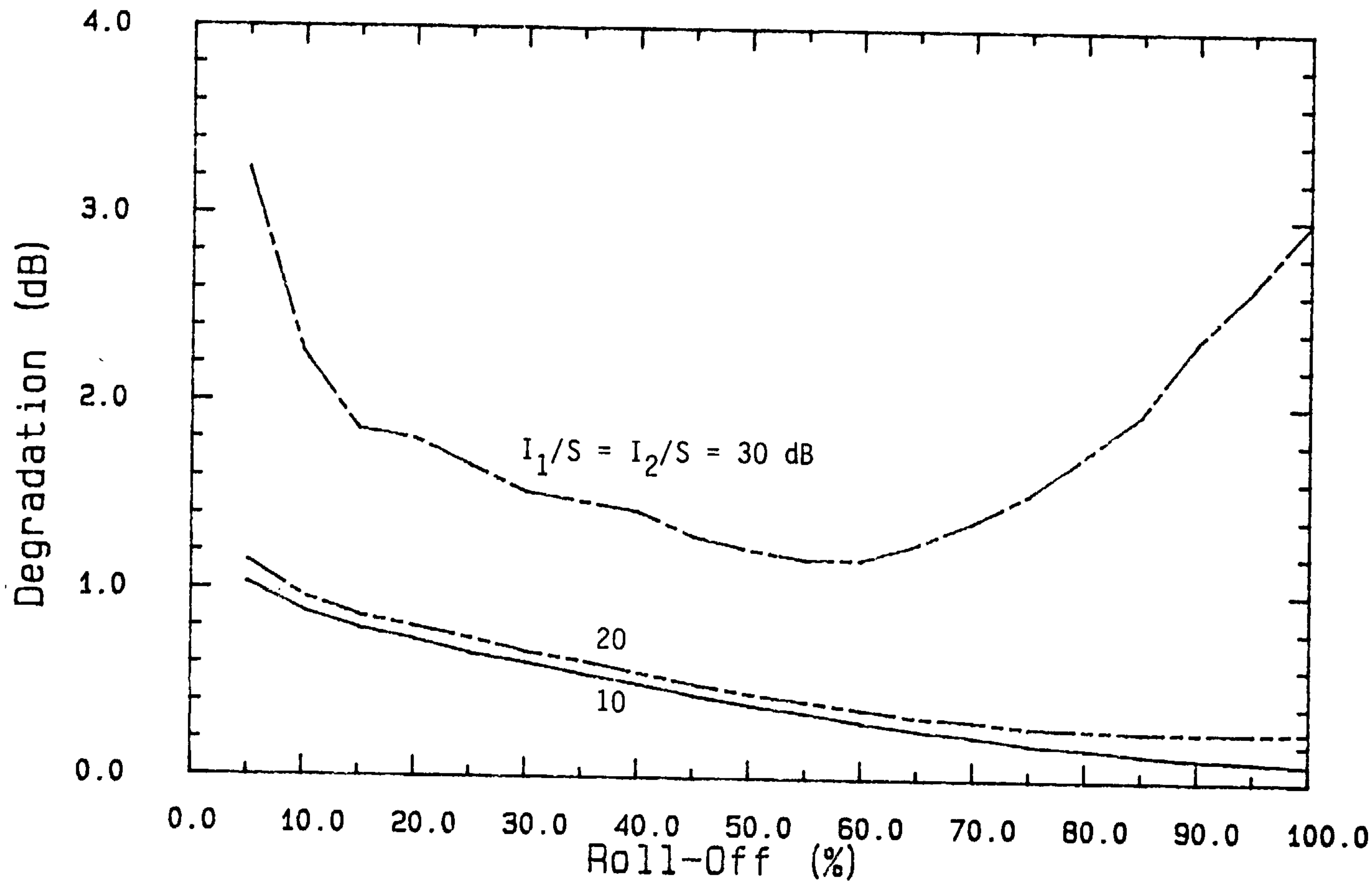

Figure 2.13 Degradation as a Function of Pulse Shaping Filter Roll-Off Factor.

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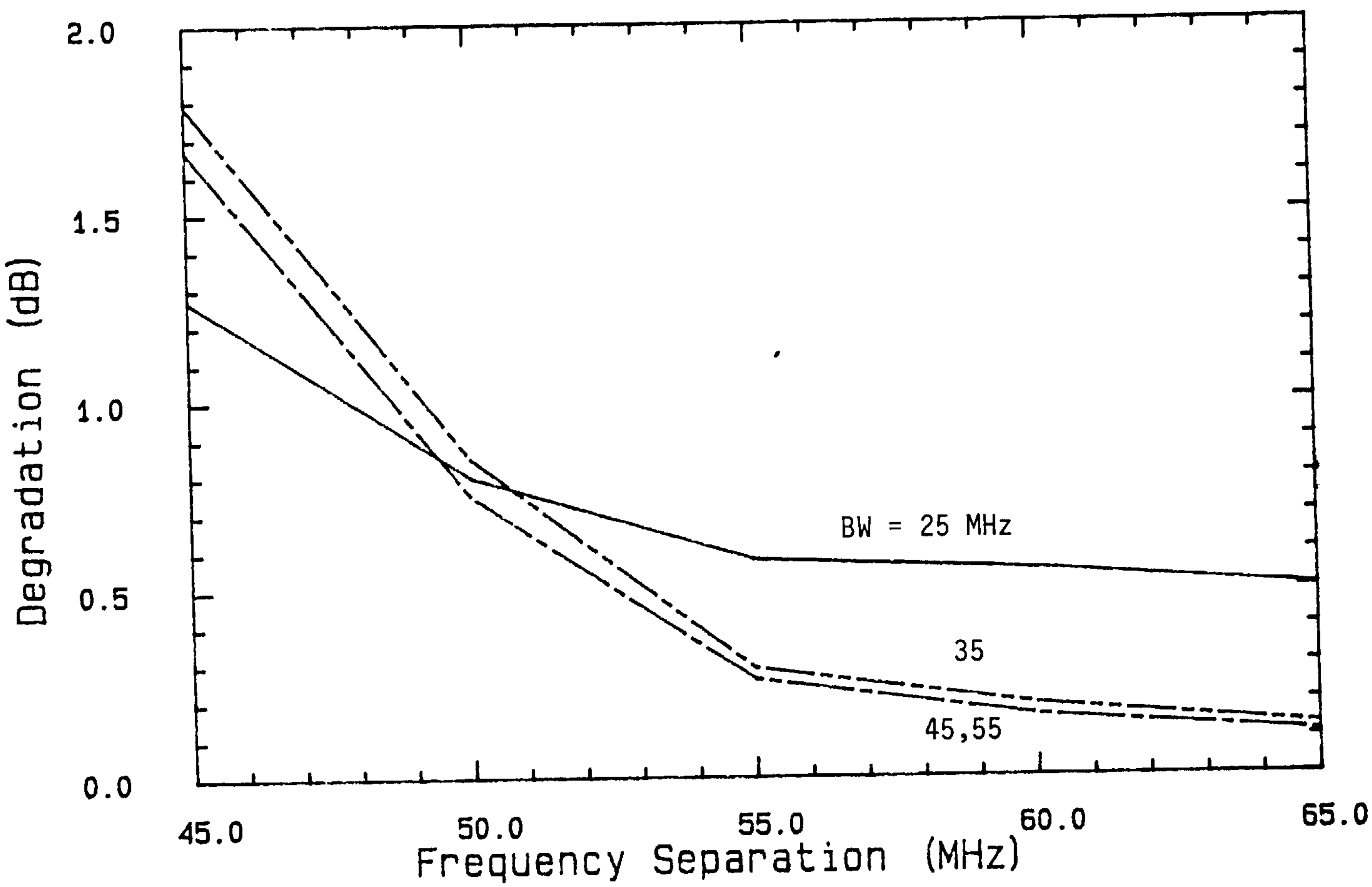

Figure 2.14 Degradation as a Function of Channel Filter Bandwidth.

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improves the performance relative to a matched filter. The decision will rely on the filter implementation complexity. Sharing a single HPA with more than one channel will seriously degrade the system performance. The performance is expected to be worse if more than three channels are sharing the HPA at the same time, since more intermodulation products will arise, and the weaker desired channel will experience more signal suppression [5].

The channel filter bandwidth and the channel separation are two major parameters to be decided. This decision, however, must be coupled with the decision on channel power control. It seems that some kind of channel power control has to be included, since the dynamic range of the ACI power can be up to 60 dB stronger. If I/S is limited to be 20 dB or less, a channel separation of 55 MHz incurs less than about 0.4 dB signal degradation, if the channel filter bandwidth is set at 45 MHz. Of course, the exact performance will heavily depend on the AM/AM and AM/PM characteristics of the HPA nonlinearity being used. Increasing channel separation can potentially relieve the ACI effect. However, since the available frequency spectrum is limited for Space Station, it may not be desirable to have a channel separation more than 60 MHz.

The transmitter output filter can also be used to suppress the out-of-band frequency components generated by the HPA (assuming one HPA for each channel). However, hardware implementation can be more complex, since it operates at the RF.

3. DESIGN AND EVALUATION OF A FUNCTIONAL COMPUTERIZED RF LINK SIMULATION/ANALYSIS SYSTEM FOR SPACE STATION

In this section, the SCSS modeling requirements and the preliminary RF link elements and the associated key parameters are described. They serve as the functional requirements of the computerized RF link simulation/analysis system.

Section 3.1 talks about the SCSS modeling requirements on the Space Station C&T system simulation, while section 3.2 discusses the definition of preliminary RF link elements and key parameters.

3.1 SCSS MODELING REQUIREMENTS ON SPACE STATION C&T SYSTEM SIMULATION

3.1.1 Introduction

In the early stage of SCSS design and development for the Space Station communication and tracking system simulation, SCSS system modeling requirements have to be known. In this section the SCSS requirements for the Space Station C&T system modeling and simulation are addressed. The requirements are derived from the JSC's documents on the Space Station. Specifically, they are:

(1) Space Station Communications and Tracking System Requirements JSC, April 18, 1985.

(2) Space Station Reference Configuration Description, JSC-19989, August 1984.

There are some discrepancies between these documents, as will be indicated later.

Section 3.1.2 will derive the SCSS C&T system modeling requirements based on the Space Station C&T systems functional requirements. Section 3.1.3 will give a more detailed description on the modeling and simulation.

3.1.2 Derivation of SCSS Modeling Requirements

The Space Station C&T functional requirements are listed in Table 3.1.1 along with the derived SCSS system modeling requirements. In the "SCSS Modeling Requirements" column, only the typical SCSS requirements are shown and will not be repeated for each item thereafter. Further discussion on the SCSS modeling requirements will be given in Section 3.

Table 3.1.1 Space Station C&T Functional and SCSS Modeling Requirements.

Space Station C&T Functional Requirements	SCSS Modeling Req.
1. Multiple duplex voice channels are required between Space Station and ground facilities. All habitable modules, berthing ports and airlocks shall have wireless voice communi- cations. The C&T design shall provide the capability to record, process, amplify, mix, recognize, synthesize, switch and distribute voice and/or audio to/from all internal locations and also provide voice conferen- cing capability between IVA, EVA, manned vehicles, and the ground.	* Standard analog and digital modulation techniques * Digital voice modeling * Hardware modeling e.g. recorder, A/D, and D/A.
2. The C&T system shall provide for the generation, processing, distribution, digitization, and transmission, storage and retrieval, and reception of TV and CCTV.	* Color TV and CCTV modeling e.g. signal compression, freeze frame, scanning speed, digitization
3. The C&T design shall provide communication and tracking between the Space Station and interoperating elements (including EMU's) whenever they are within line of sight and within the maximum distance.	* Link budgets of different interoperating elements
4. The C&T system shall provide acquisition and tracking of all detached vehicles for rendezvous, approach, departure, berthing, traffic control, and co-orbiting operations. It shall provide information to determine target vehicle state vectors including attitude where required. All SSPE's and participating free-flyers shall coopera- tively support tracking by the Space Station. No spcial capability shall be added to the tracking system specifically for collision warning.	* Antenna acqui- sition and tracking * Signal acquisi- tion and tracking * Antenna blockage * Space Station multipath study * Target vehicle state vectors (simulation and/ or real time)
5. The C&T system shall not preclude the addition by users of secondary communication links independent of TDRSS/TDASS to the ground. This data link shall be able to support user-unique communications require- ments consistent with the Space Station compatibility constraints in terms of EMI and RFI requirements.	* TDRSS/TDASS link modeling * User-unique communication links modeling * RFI and EMI modeling

Table 3.1.1 Continued.

6. Communications between the ground and the Space Station and Space Platform shall be through the TDRSS or its replacement system. The use of the maximum TDRSS transmitted and received data rates over both the Ku band and the S band single access links shall be provided for. Data rates in excess of the maximum shall be transmitted as individual data streams to the ground independent of TDRSS and TDASS using payload provided systems. Provisions shall be made for a contingency command and telemetry links to the ground from the Space Station and Space Platforms.	* Payload provided systems modeling * Contingency command and telemetry links modeling
7. The C&T system shall provide for acquisition, signal processing, distribution, and transmission of customer data. Flight and ground data systems supporting payloads shall be transparent to the customer.	* Signal processing * Signal multiplexing and demultiplexing
8. The C&T system shall include provisions which prevent unauthorized access to uplinks and downlinks and to all operational links as required. C&T shall provide links for command authentication, but command authentication, per se, shall be the responsibility of the subsystem receiving the command. This protection shall include data and command privacy and does not include anti-jamming provisions.	* Data encryption modeling * Command authentication
9. The C&T system shall provide for crew members to communicate privately with the ground. This private communications link shall include both audio and video data.	* Data encryption for audio and video data (high and low data rates)
10. The C&T system shall provide for reception and processing GPS navigational signals.	* GPS link reception and processing
11. The C&T system shall provide for simultaneous target vehicle tracking and communications.	* Antenna multiple access tracking techniques e.g. phased array, MBA * Multiple Access communication techniques e.g. FDMA, TDMA, CDMA

Table 3.1.1 Continued.

12. Provisions shall be made for controlling and monitoring the C&T system in conjunction with the Data Management System (DMS)	* N/A in this study phase
13. Space Station Program (SSP) flight and ground command and data system supporting payloads shall be transparent to the customer. The SSPE's shall provide transparent paths for commands and data between a payload and a customer in a manner that does not require the SSP to develop mission-unique software.	* N/A in this study phase
14. Multifunctional displays and controls shall be used. The use of manually operated switches shall be minimized. Controls shall be protected against inadvertent operation. The following shall be designed to facilitate human productivity: character size, display brightness and contrast, auditory characteristics; control size, direction of motion, and types of controls; display format characteristics such as use of color, color coding, and graphic versus textual display; feedback to the operator from controls, including tactile, visual, and auditory feedback requirements. Emergency operation of controls shall have a shape, texture, and location that is readily identifiable in the dark.	* N/A in this study phase. However, the idea can be adopted in the SCSS input/output
15. The C&T system shall provide for safe haven communications with the ground and SSO from any of the inhabitable modules for a maximum period of 28 days.	* SSO link modeling

3.1.3 SCSS Modeling Requirements

Based on the derived SCSS modeling requirements obtained in Section 3.1.2 and some other requirements in the referenced documents, a more detailed SCSS modeling requirements are investigated. The SCSS requirements are divided into two categories, generic and link specific. The generic category will contain all the generic communication components to be implemented in the SCSS generic structure. The link specific category will contain the communication link specific components like TDRSS, EVA, SSO, and Free-Flyers. These specific links will be modeled and stored in the SCSS for frequent usage so that a user need not has to create it everytime when they are used.

The SCSS requirements to be discussed are only typical in each component, and not intend to be exhaustive. The flexibility of the SCSS structure will allow new items to be implemented in the model library in a convenient manner.

3.1.3.1 Generic Model

3.1.3.1.1 Link Power Budget

Link power budget is a fundamental and yet important quantity to be considered in space communication. In order to compute this quantity, a lot of information about the end-to-end link have to be known. The computation of this quantity may be complex if relative motion between the transmitter and receiver is not negligible. Simulated or probably real-time data of relative motion has to be available in the SCSS modeling.

3.1.3.1.2 Modulation Techniques

Due to the wide spectrum of the communication requirements in the Space Station scenario, a large number of communication modulation techniques have to be modeled in the SCSS. These modulation models may include both analog and digital techniques, although digital modulation will be primarily important. Typical coherent and noncoherent digital modulation schemes may include MPSK, MSK, FSK, CPM, ASK, and QAM. Some modulation techniques are bandwidth efficient while some others are best suitable for nonlinear channels. In order to simulate a link under different conditions a complete model library of modulation techniques will be necessary.

3.1.3.1.3 Multiple Access Schemes

Multiple access scheme is usally a complicated issue to be considered in space communications design, since its choice may affect other issues such as user interference and synchronization. Typical schemes like FDMA, TDMA, CDMA, and FHMA will be modeled.

3.1.3.1.4 Formatting/Source Coding

Formatting of digital data involves any operation which transforms baseband signal into digital symbols. These operations will inlcude sampling, quantization, and PCM coding. Source coding will involve data compression in addition to formatting. These kinds of operations are important when digital voice and television are to be modeled in the Space Station C&T link. Redundant data is to be elimintated in order to use the channel bandwidth efficiently. Source coding/formatting to be modeled includes A/D processing, PCM formats (NRZ, Manchester, Miller), differential PCM, delta modulation, and linear predictive coding etc.

3.1.3.1.5 Channel Coding

Channel coding can be divided into two groups, waveform coding and structured sequences. Waveform coding refers to signal design such that the detection process can be less subject to the noise distortion. Examples of waveform coding are orthogonal, biorthogonal, and simplex codes. Channel coding with structured sequence is a method of inserting redundancy into the source data sequence such that errors occurred in transmission can be identified and/or corrected. Examples of channel coding with structured sequence are block and convolutional codes. SCSS simulation in this category will be mostly devoted to structured sequences. Specific cases will be modeling the coders and decoders of Reed-Solomon codes and convolutional codes with Viterbi decoders.

3.1.3.1.6 Antenna

Antenna system is another major category in C&T simulation. The Space Station antenna systems will be highly complex and consist of various types. Typical antenna types are reflector antenna, multiple beam antenna, phased array antenna, and microstrip antenna. Antenna signal processing will include target acquisition and tracking and interference rejection. Antenna switching effect will also be of interest to system engineers.

3.1.3.1.7 Synchronization

Signal acquisition and tracking are important in both coherent and noncoherent communication systems. Acquisition and tracking techniques (tracking loops) and their performance (e.g. acquisition time, signal degradation) on one or two way communication links have to be studied. Carrier, bit, word, frame, and network synchronization are areas of interest in SCSS.

3.1.3.1.8 Signal Distortion Modeling

Signal distortion can occur anywhere in the transmitter, channel, or receiver due to noise, interference, nonlinearity, finite bandwidth, spacecraft motion, and other factors. The signal distortion can be acceptable or severe depending on situations. There are over 20 signal distortion parameters to be modeled in the C&T simulation. Examples of these parameters are data asymmetry, phase nonlinearity, AM/AM, AM/PM, data transition time, gain imbalance, phase imbalance, gain flatness, frequency stability, phase noise, and data bit jitter.

3.1.3.1.9 Hardware Modeling

Hardware modeling will be essential in detailed C&T link modeling and simulation. It can be in subsystem and component levels. Subsystem hardware modeling includes acquisition and tracking subsystems, ranging subsystem, television, audio and video recorders and others. Component level hardware may include A/D, D/A, samplers, quantizers, scramblers/descramblers, multiplexers/demultiplexers, filters, phase detectors, oscillators, and power amplifiers etc.

3.1.3.1.10 Optical Communication

Optical communication can be implemented in two ways, with and without guided medium. Space cross-link communication is an example of unguided system, while guided system makes use of optical fiber. Space Station will use optical system for ranging during the docking operation. Optical fiber network will be used as an intra-Space Station data distribution system. Optical communication system is a complex system involving many hardware parameters. SCSS simulatin will help in modeling these systems.

3.1.3.1.11 Spacecraft Dynamics and Trajectory Modeling

The spacecraft dynamics and trajectory data, obtained in real-time or from simulation, is essential in monitoring the Space Station C&T performance as a function of time. Depending on the spacecraft dynamics C&T performance may vary tremendously. Communication link will be broken when a spacecraft moves away from the line-of-sight path of the Space Station antenna. Graphic display will be very helpful in determining the spacecraft dynamics and trajectory.

3.1.3.1.12 Multipath Modeling and Antenna Blockage

Multipath effect due to the signal reflection of the Space Station and other parked vehicles may yield signal fading which is undesirable to the Space Station C&T performance. Determining multipath effect requires the knowledge of the antenna locations and the shape of the Space Station and parked vehicles. SCSS will store all the combinations of the parked vehicles in order to deal with different situations. The antenna locations will also determine whether there is any blockage by other parts of the body or the parked vehicles.

3.1.3.1.13 Atmospheric Channel Environment Modeling

The atmospheric channel environment is an important factor in determining the space to/from ground C&T performance. For the TDRSS to/from ground link this channel will cause signal fading and dispersion. The channel may vary from season to season and from day to day. A data base, statistical and/or detailed, of the atmospheric environment can be stored in SCSS.

3.1.3.1.14 RFI, EMI, & Jamming Modeling

Radio frequency interference, Electromagnetic interference, and jamming can cause serious interference to the desired signals of the C&T systems. RFI comes from unintentional multiple users and other sources, while jamming comes from intentional interfering sources. EMI is due to local electromagnetic power sources. Statistical modeling of these interferences are necessary in predicting the susceptibility of the C&T system to the interferences.

3.1.3.2 Specific Link Modeling

3.1.3.2.1 SS-TDRS Link

The TDRS will serve as a communication relay between the Space Station and ground. It will support the single access voice, telemetry, commands, wideband data, television, and text and graphics. S band and Ku band frequency will be used to support the low and high data rates respectively.

The K band single access (KSA) link will use BPSK, QPSK, or SQPSK modulation, with or without PN spread, with or without convolutional code, and NRZ baseband signaling. The same conditions apply to the S band single access (SSA) link. The transmit and recieve links will have different requirements.

3.1.3.2.2 SS-Orbiter Link

The Space Station-Orbiter communication link will make use of the S band and K band multiple access low data rate system. It will support the telemetry, command, and voice capability. The tracking link will use the Ku band ranging system for range, range rate, azimuth, elevation, and angle rate.

3.1.3.2.3 SS-EVA/MMU Link

The communication link will use the Ku (or K ? Note that there is a discrepancy in the frequency band used between the two referenced documents.) band multiple access system. It will support the command, telemetry, voice, and television in the proximity operations. The tracking system will use the GPS position data.

3.1.3.2.4 SS-Free Flyer Link

The communication link will use the Ku (or K ?) band multiple access system for far range low and high data rate communication. It will support the command, telemetry, data, and television. The tracking link will make use of the GPS position data.

3.1.3.2.5 SS-Platform Link

This link will be the same as the SS-Free Flyer link.

3.1.3.2.6 SS-OMV Link

The SS-OMV communication link will use the Ku (or K ?) band multiple access system and high data rate system for proximity operations. It will support the command, telemetry, and television. The tracking link will use the Ku band ranging system for range, range rate, azimuth, elevation, and angle rate.

3.1.3.2.7 SS-OTV Link

This link will be the same as the SS-OMV link (?).

3.1.3.2.8 SS-MRMS Link

This link will use the Ku (or S ?) band multiple access (or dedicated ?) system for command, telemetry, and television.

3.1.3.2.9 SS-Docking Vehicles

Optical ranging systems will be used for docking vehicles. It will support the range, range-rate, azimuth, elevation, and attitude when the vehicle is within 1000 feet.

3.2 DEFINITION OF PRELIMINARY RF LINK ELEMENTS AND KEY PARAMETERS

3.2.1 Introduction

In designing a communication and tacking system modeling and simulation system, most of the effort will be spent on developing the Model Library which contains the building blocks of C&T systems. Developing the Model Library in turn will require a systematic design of the library structure. The interrelationship among the numerous building blocks and the associated paramters of the Model Library have to be defined. It is the intention of this report to define some typical digital C&T models and their parameters which will be used in SCSS. This preliminary definition will be in a level to support the next phase Space Station R&D work. Detailed hardware parameter definition will not be included here.

3.2.2 RF Link Model

In this section, the typical RF communication and tracking links to be modeled in SCSS are discussed. They will be in the level of C&T building blocks. Possible combinations of the building blocks are listed. With the help of this discussion, typical user defined C&T links to be modeled by SCSS can be visualized.

The building blocks can be divided into the following categories as depicted in Fig. 3.2.1: formatting, source coding, interleaving, scrambling, encryption, waveform coding, structured sequences, modulation, multiplexing, multiple access, spreading,

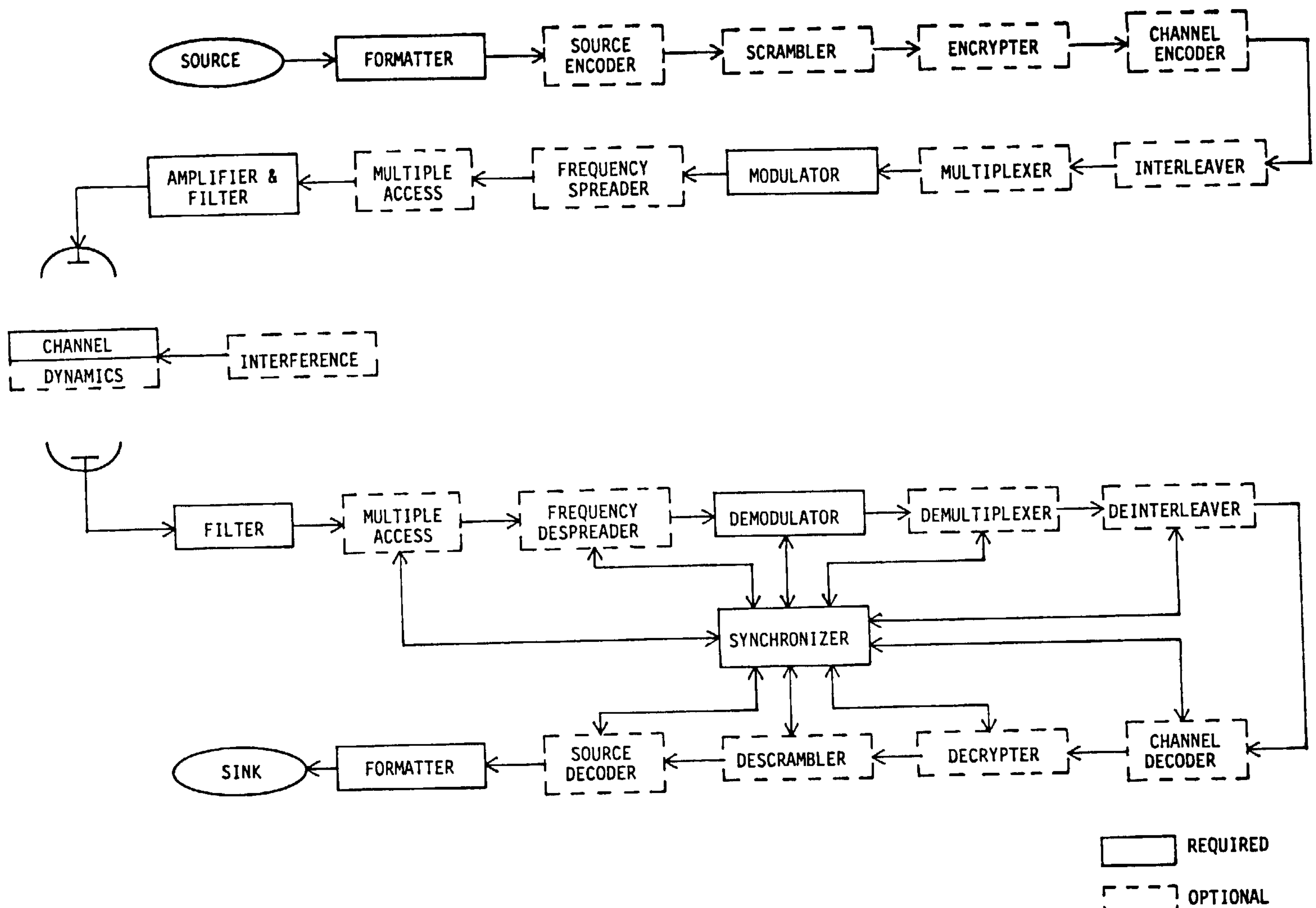

Figure 3.2.1 Typical Communication System Block Diagram.

filtering, nonlinearity, antenna, interferences, channel characterization, dynamics, despreading, synchronization, demultiplexing, demodulation, data detection, channel decoding, decryption, descrambling, deinterleaving, and source decoding. The blocks in solid line are required system blocks in a link, while the blocks in dotted line are optional system blocks. The optional system blocks can be present or absent in a C&T link in any fashion. However, the counterpart in the receiver has to match with the optional block in the transmitter, e.g. channel decoder has to match with channel encoder. In building a C&T link, these blocks will be chosen according to the application and complexity of the link.

3.2.2.1 Formatting/Source Coding

This category performs the functions of analog to digital conversion with the option of removing source redundancy, and put the digitized data into a desired digital data format. It includes the components such as sampling, quantization, pulse code modulation (NRZ, Manchester, Miller), partial response coding, differential pulse code modulation, delta modulation, linear predictive coding, Huffman coding, and character coding etc.

3.2.2.2 Interleaving

Data interleaver can be used to fight burst errors. Before encoding, data can be first interleaved. Received data will be deinterleaved before it is decoded. In this case, all burst errors will be broken down into errors with much shorter length, and can be in turn corrected by error correcting codes. Data interleaving can be included with specified algorithms.

3.2.2.3 Scrambling

Digital data scrambling is used to increase the data transition density in case of NRZ or RZ PCM waveforms are used. With the help of data scrambling, symbol synchronizers in the receivers can be ensured to function under the conditions of very low transition density.

3.2.2.4 Encryption

Data encryption is used to protect the data content by mapping the original data to some unrecognized data format. This category may not be of interest in SCSS since we are of interest to the C&T link performance rather than the data content.

3.2.2.5 Waveform Coding

This category includes the waveform coding methods like M-ary, orthogonal, biorthogonal, transorthogonal, and L-orthogonal signaling. These waveform codes possess different "distance" property. Although waveform coding possesses some kinds of coding properties, it is not treated as a major method for error correction.

3.2.2.6 Structured Sequences

Structured sequences play the major role of error correction. Structured redundancy is inserted into the source data so that errors can be detected and corected. In general, they are divided into two groups, block code and convolutional code. Among them, the Reed-Solomon code and the convolutional code with

Viterbi decoding are the most widely used.

3.2.2.7 Modulation

Digital modulation can be divided into coherent and noncoherent. Examples of coherent digital modulation are phase shift keying, frequency shift keying, amplitude shift keying, offset QPSK, minimum shift keying, and continuous phase modulation. Noncoherent digital modulation schemes include frequency shift keying, differential phase shift keying, amplitude shift keying, and their hybrids.

3.2.2.8 Multiplexing

Multiplexing is a process to combine different independent signals together to share common communication resource. Examples of multiplexing will include time division multiplexing and frequency division multiplexing.

3.2.2.9 Multiple Access

Multiple accessing is a process to combine signals from different users, usually in different locations, to share common communication resource. Examples will include time division multiple access, frequency division multiple access, and code division multiple access.

3.2.2.10 Spreading

Spread Spectrum techniques can be used for interference rejection, ranging, privacy, selective addressing, and multiple access etc. Typical spread spectrum techniques include PN spread, frequency spread, time spread, and their hybrids.

3.2.2.11 Filtering

Filtering is used to process signals to achieve certain system functions like bandwidth limitation, pulse shaping, matched filtering, and signal weighting. Analog and digital filters will be considered.

3.2.2.12 Nonlinearity

Nonlinear devices are common in C&T links and are in general not easily to be analyzed. Except for certain devices, simulation will be required. Nonlinearity in SCSS will typically include hard limiter, TWTA, nth power devices, and compandor etc.

3.2.2.13 Antenna

Antenna is a major C&T subsystem and involves a lot of effort in modeling. While modeling an ideal standalone parabolic antenna can be trivial, modeling an antenna in a real environment could be difficult. Modeling a complex antenna system such as phased-array and multiple beam antenna will require more effort. Microstrip antenna will be included in SCSS.

3.2.2.14 Interferences

Interferences in C&T systems could include radio frequency interference, electromagnetic interference, and jamming. Another class of signal interference will be intersymbol interference, cochannel interference, and cross channel interference.

3.2.2.15 Channel Characterization

Channel characterization will identify channel environment such as blockage and multipath due to Space Station and other spacecrafts. It also includes the signal degradation due to the channel, e.g. atmospheric absorption, fading, and dispersion.

3.2.2.16 Dynamics

Spacecraft dynamics will create relative motion between transmitter and receiver, and in turn will affect the synchronization between them. Dynamics such as rotation will change the direction of the antenna pointing. As a result, signal blockage could occur.

3.2.2.17 Despreading

Despreading will introduce signal degradation due to the lack of perfect match of timing and waveform. Performance of despreading algorithms will be modeled.

3.2.2.18 Synchronization

Synchronization in time and frequency is one of the most important C&T subsystem. Synchronization in carrier, symbol, word, frame, and network are areas of interest. Both acquisition and tracking performance will be evaluated. Since synchronization performance is dependent on specific synchronizers, modeling of individual synchronizer will be required.

3.2.2.19 Demultiplexing

Demultiplexing is the inverse of the multiplexing process and may involve some filtering. Processing loss may arise.

3.2.2.20 Demodulation

Demodulation could be complex in order to minimize data error. It may couple with the synchronization process. Effects of signal equalization and automatic gain control are included.

3.2.2.21 Data Detection

Data detection is the final signal processing procedure to extract encoded data out of the received signal after demodulation is completed.

3.2.2.22 Channel Decoding

Channel decoding is the inverse process of channel encoding to extract data from the encoded data. Decoding algorithms depend on the specific codes used. Decoders like Reed-Solomon decoder, Viterbi decoders with hard and soft limiters, and for other commonly used codes will be modeled.

3.2.2.23 Decryption

Decryption is the inverse process of encryption to extract data out of the encrypted data sequence. Operations of substitution, permutation, and shift register feedback will be typical.

3.2.2.24 Descrambler

Descrambler is used to put the symbols in the right order in case a scrambler is used in the transmitter.

3.2.2.25 Deinterleaver

Deinterleaver is the one required to put the data back in order when an interleaver is used in the transmitter.

3.2.2.26 Source Decoding

This block will perform the final signal processing procedure to recover the original data or signal. The procedure will depend on the original signal format, analog or digital. It also depends on the actions performed in the source coding/formatting block.

3.2.3 Model Parameters

In this section the typical system paramters of the above C&T components are provided. They are in the system engineering level and not as detail as the hardware level. SCSS modeling will use these parameters as a guideline. Detailed parameters will be considered at the time of detailed hardware modeling.

3.2.3.1 Formatting/Source Coding

3.2.3.1.1 Character Coding:

Coding Types:

American Standard Code for Information Interchange (ASCII), Extended Binary Coded Decimal Interchange Code (EBCDIC), and International Telegraph Alphabet Number 2.

3.2.3.1.2 Sampling

System Parameters:

Sampling rate (sampling frequency, sampling time), and sampling signal.

3.2.3.1.3 Quantization

Quantization Types:

Linear (uniform) and nonlinear (compander) quantization, optimal and suboptimal quantization, adaptive PCM, delta modulation, and differential PCM (linear predictive quantization).

System Parameters:

Number of quantization levels, quantization distortion, quantization noise (granular quantizing noise, slope overload noise), dynamic range, and dither signal.

3.2.3.1.4 <u>Pulse Code Modulation</u>

PCM Types:

NRZ, Manchester, and Miller.

System Parameters:

Bandwidth, pulse shape distortion (rise time, fall time, ripple, pulse width variation), and pulse period.

3.2.3.1.5 <u>Other Signals</u>

Signal Types:

Partial response signals (duobinary signal, modified duobinary signal), differential pulse code modulation, delta modulation, linear predictive coding, and Huffman coding, etc.

3.2.3.2 <u>Interleaving</u>

Interleaving Types:

Various interleaving algorithms.

System Parameters:

Degree of interleaving.

3.2.3.3 <u>Scrambler</u>

Scrambler Types:

Shift register types.

System Parameters:

Tapped connections.

3.2.3.4 <u>Encryption</u>

Encryption Types:

Substitution ciphers, transposition ciphers, data encryption standard, stream encryption, key protection, encryption by large primes, and Knapsack algorithm.

System Parameters:

Encryption key (integer, character stream, bit stream, large prime numbers).

3.2.3.5 Waveform Coding

Waveform Types:

Various signal waveform.

System Parameters:

Corresponding distances among signals.

3.2.3.6 Structured Sequences

3.2.3.6.1 Block Code:

Code Types:

Hamming, Cyclic, Shortened Cyclic, Cyclic Hamming, Golay, BCH, Reed-Solomon, Reed-Muller, Burst Error Correcting Cyclic, Product, Interleaved, Fire, Modified Fire.

System Parameters:

Code length, number of information bits, minimum distance, generator polynomial in a cyclic code.

3.2.3.6.2 Convolutional Code:

System Parameters:

Number of inputs, number of outputs, number of input memory (constraint length, code rate), generator polynomials, coding gain.

3.2.3.6.3 Concatenated Code:

A combination of two codes, an inner code and an outer code. System parameters depend on the code types used. A commonly used concatenated code consists of Reed-Solomon code as an outer code and convolutional code as an inner code.

3.2.3.7 Modulation

Digital Modulation Types:

Coherent or noncoherent, number of phase levels, number of amplitude levels, and number of frequency levels.

System Parameters:

Bandwidth, data rate, signal strength, phase imbalance, gain imbalance, relative phase in quadrature channels, data asymmetry, data transition time, transition density, phase nonlinearity, gain flatness, gain slope, data transition induced phase modulation, PN chip jitter, data bit jitter, spurious phase modulation, incidental amplitude modulation, PN asymmetry, and PN skew.

3.2.3.8 Multiplexing

Multiplexing Type:

Time division multiplexing, frequency division multiplexing, space division multiplexing, statistical time division multiplexing, and wavelength division multiplexing.

System Parameters:

Number of signal sources, number of slots, data rates, bandwidth, sampling rates, sample and hold circuit characteristics, and synchronization.

3.2.3.9 Multiple Access

Multiple Access Types:

Time Division Multiple Access (TDMA), Frequency Division Multiple Access (FDMA), Code Division Multiple Access (CDMA), Space Division Multiple Access (SDMA), Polarization Division Multiple Access (PDMA), and Demand Assignment Multiple Access (DAMA).

System Parameters:

Number of users, number of channels, transponder bandwidth, channel bandwidth, antenna stucture, code types, data rates, guardband, guardtime, burst rate, buffer size, and frame period.

3.2.3.10 Spreading

Spreading Types:

Spread spectrum with direct sequence, spread spectrum with frequency hopping, spread spectrum with time hopping, and their hybrids.

System Parameters:

Baseband signal types, processing gain, jammer type, jammer to signal ratio, signal to noise ratio, bandwidth, filtering, data rate, probability of error, probability of interference, and squaring loss.

3.2.3.11 Filtering

Filter Types:

Analog or digital, RC, Butterworth, Chebyshev, Bessel, Elliptic, lowpass, bandpass, highpass, bandstop, FIR, and

IIR.

System Parameters:

Finite word length effect, filter order, 3 dB bandwidth, cutoff frequency, ripple, group delay, and phase linearity.

3.2.3.12 Nonlinearity

Nonlinearity Types:

Hardlimiters, square law bandpass, nth power law half wave and full wave devices, half wave linear bandpass, and TWTA.

System Parameters:

Nonlinear waveform distortion (AM/AM, AM/PM).

3.2.3.13 Antenna

Antenna Types:

Parabolic, multistrip, multiple beam, adaptive phase array, monopulse, antenna autotrack.

System Parameters:

Antenna size, antenna pointing, antenna pattern (antenna gain, sidelobes, nulls), polarization, axial ratio, beam switching, antenna switching, antenna dynamics, and antenna acquisition and tracking performance.

3.2.3.14 Interferences

Interference Types:

RFI, EMI, jamming, ISI, cochannel and crosschannel interferences.

System Parameters:

Pulse jamming, tone jamming, broadband jamming, bandwidth, duty cycle, and interference strength.

3.2.3.15 Channel Characterization

Channel Characterization:

Multipath, and atmospheric effect (absorption, fading, dispersion).

System Parameters:

Signal degradation, interference, signal strength variation (fast and slow), signal waveform distortion, time dispersion, and frequency dispersion.

3.2.3.16 Dynamics

Dynamics Types:

Relative motion (rotation, orientation and distance variation).

System Parameters:

Antenna blockage, antenna switching, angular rotation (roll, yaw, pitch), transient effect, velocity, and acceleration.

3.2.3.17 Despreading

Despreading Types:

Spectrum despreading with direct sequence, spectrum despreading with frequency hopping, spectrum despreading with time hopping, and their hybrids.

System Parameters:

Baseband signal types, processing gain, jammer type, jammer to signal ratio, signal to noise ratio, bandwidth, filtering, data rate, probability of error, probability of interference, and squaring loss.

3.2.3.18 Synchronization

Synchronization Types:

Carrier, bit, word, frame, and network.

Synchronization Loop Types:

Acquisition or tracking, Costas Loop, Squaring Loop, Frequency Lock Loop, Delay Lock Loop, Fixed and Variable Dwell Time PN Acquisition, DTTL, and Early Late Gate.

System Parameters:

Acquisition time, reacquisition time, acquisition range, false lock probability, loss of lock probability, drop lock probability, tracking error probability density function, tracking offset, phase jitter, cycle slipping, doppler tracking accuracy, ranging accuracy, squaring loss, and probability of erroneous frame synchronization.

3.2.3.19 Demultiplexing

Demultiplexing Types:

Time division demultiplexing, frequency division demultiplexing, space division demultiplexing, statistical time division demultiplexing, and wavelength division demultiplexing.

System Parameters:

Number of signal sources, number of slots, data rates, bandwidth, sampling rates, sample and hold circuit characteristics, and synchronization.

3.2.3.20 Demodulation

System Parameters:

System parameters as discussed in the Modulation section, pulse dispersion, delay distortion, phase noise, bit energy to noise power spectral density ratio, bandwidth, spurious outputs, frequency stability, signal strength variation, PN chip rate error, data rate error, power split error, equalization, and automatic gain control.

3.2.3.21 <u>Data Detection</u>

Detection Types:

Matched filters, integrate and dump, and threshold detectors.

System Parameters:

Hard limiting effect, signal to noise ratio, phase noise, waveform distortion, and ambiguity.

3.2.3.22 <u>Channel Decoding</u>

3.2.3.22.1 <u>Block Code:</u>

Decoding Algorithms:

Syndrome Computation, Error Trapping, Majority Logic (one step, multiple step), Minimum Distance, Table Look Up, and other specific code decoding methods.

System Parameters:

Decoder memory, decoder synchronization, and decoder speed.

3.2.3.22.2 <u>Convolutional Code:</u>

Decoding Algorithms:

Majority Logic, Sequential, Maximum Likelihood, and Viterbi (hard and soft decision).

System Parameters:

Decoder memory, decoder synchronization, and decoder speed.

3.2.3.23 Decryption

Decryption Types:

Substitution deciphers, transposition deciphers, data decryption standard, stream decryption, key retrieval, decryption by large primes, and Knapsack algorithm.

System Parameters:

Decryption key (integer, character stream, bit stream, large prime numbers).

3.2.3.24 Descrambler

Desrambler Types:

Shift registers types.

System Parameters:

Tapped connections and signal degradation.

3.2.3.25 Deinterleaver

Deinterleaving Types:

Deinterleaving algorithms corresponding to the interleaving algorithms.

System Parameters:

Degree of interleaving.

3.2.3.26 Source Decoding

Source Decoding Types:

Character decoding, smoothing, and digital to analog converter.

System Parameters:

Bandwidth, number of quantization levels, and data rate.

4. DESIGN AND EVALUATION OF SIMULATION SYSTEM ARCHITEXTURE

4.1 Introduction

In this section the detailed design and evaluation of the simulation system architecture of the NASA JSC Space Communications Simulation System (SCSS) is presented. This simulation system architecture is intended to serve as a tentative guideline for the SCSS software development in the next phase.

The SCSS design given here is a generic computer analysis/ simulation system for the Space Station end-to-end communication links. It provides system engineers a capability to analyze the RF C&T link building blocks such as modulators, demodulators, antennas, coders, decoders, channel characteristics, etc. It will be used to analyze the effects of single access, multiple access, coding, nonlinearity, channel and hardware characteristics, signal multiplexing, synchronization, and others.

The SCSS software will allow a user to have maximum flexibility in configuring a C&T end-to-end link. Convenient I/O interface for parameter inputs, model setup, signal flow control, and output display are considered. It will be highly reliable and provide all kinds of error control.

The SCSS system will be developed in the VAX/VMS operating system using primarily the VAX 11 FORTRAN language. The overall control procedure will be using the VMS command language.

Section 4.2 presents in general the SCSS system architecture and its functional requirements. System block diagrams are given to show the high level overall structure of the SCSS. The SCSS consists of fourteen system blocks divided into seven subsystems. Each system block serves its own specific functions and interacts with other system blocks in the SCSS. The functional requirements of each system block are discussed.

4.2 SCSS Architecture and Functional Requirements

Figure 4.1a shows the SCSS system architecture block diagram in a subsystem level. The SCSS is divided into the Control Procedure, Input/Output Subsystem, Modeling Subsystem, Control and Executive, Model and Data Subsystem, User Dynamics Subsystem, and the Array Processor.

The Control Procedure (CP) is an overall high level SCSS controller. It is in the operating system command level and is written in the VMS command language.

The Input/Output Subsystem (IOS) is a user interface subsystem between the SCSS and the users.

The Modeling Subsystem (MS) performs the C&T link construction.

The Control and Executive Subsystem (CES) is an executable module performing low level SCSS control and C&T model execution. It controls the evaluation and optimization of a C&T link simulation in a logical and efficient manner.

The Model and Data Subsystem (MDS) contains all the C&T model modules, data base, and other files necessary for the SCSS execution. It is essentially a storage subsystem.

The User Dynamics Subsystem (UDS) generates all the user dynamics data required for simulation.

The Array Processor (AP) is a hardware subsystem used to speed up the numerical computation.

Figure 4.1b is a detailed SCSS block diagram showing all the system blocks within each subsystem. The IOS consists of the

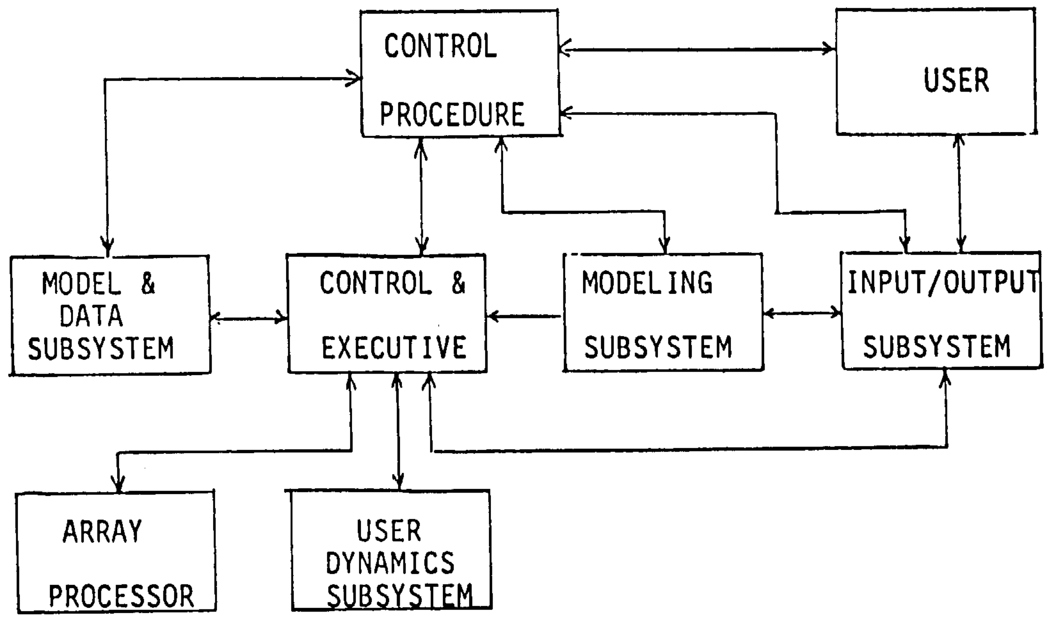

Figure 4.1a SCSS Block Diagram in Subsystem Level.

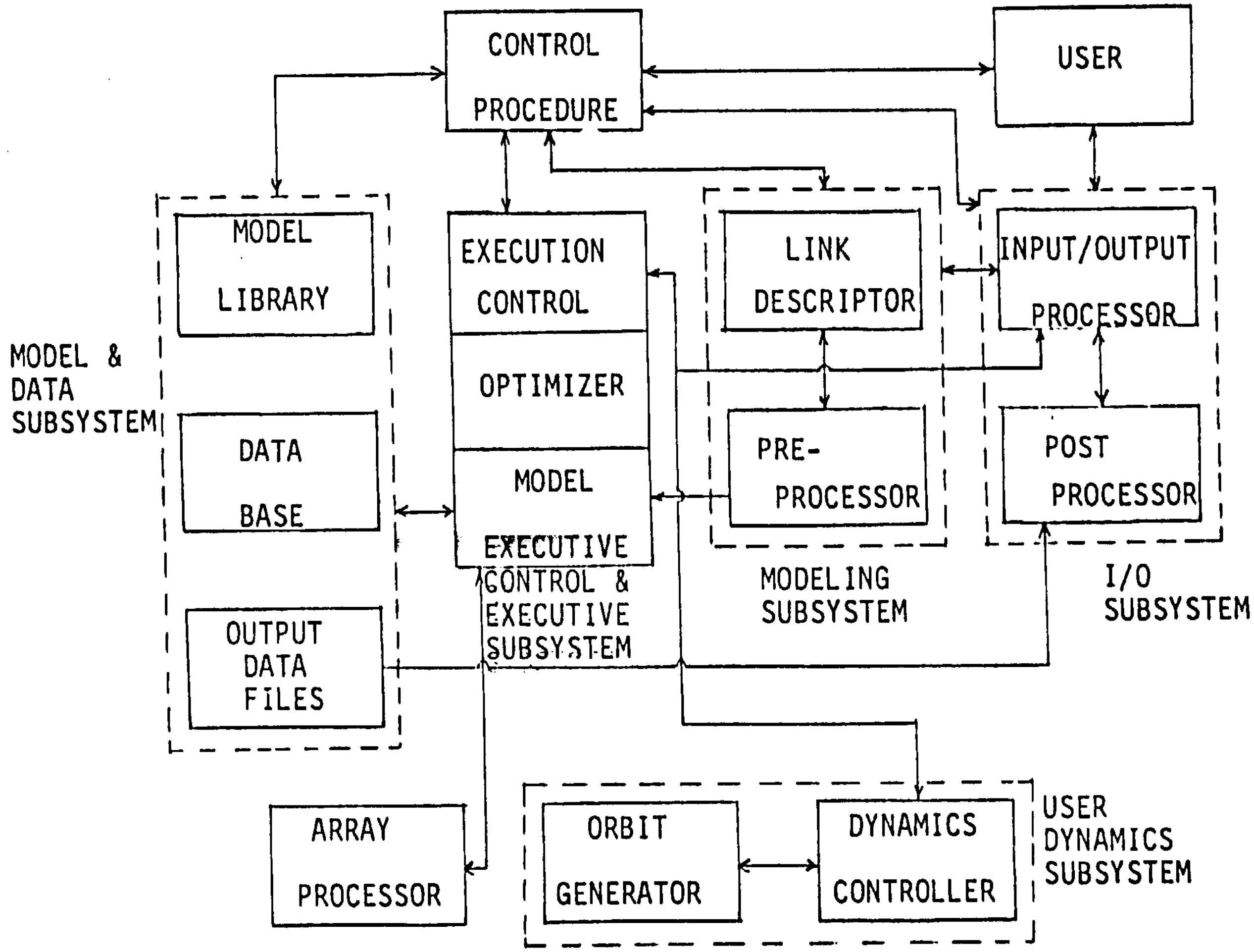

Figure 4.1b Detailed SCSS Block Diagram.

Input/Output Processor (IOP) and Post-Processor (POP). The MS consists of the Link Descriptor (LD) and Pre-Processor (PRP). The CES consists of three major sections, the Execution Control (EC), the Optimizer (OP), and the Model Executive (ME). The MDS consists of the Model Library (ML), Data Base (DB), and Output Data Files (ODF). The UDS consists of the Orbit Generator (OG) and Dynamics Controller (DC).

The CES is itself an executable module containing three major sections. The EC and OP sections are fixed modules residing in the SCSS. The third section, ME, is a dynamic module to be created by the Pre-Processor. The ME is different for different C&T link configuration and evaluation approach. The two fixed modules, EC and OP, are then put together along with the ME to form the CES module. Fig. 4.2 shows the procedure of forming the module CES.

The detailed description of the SCSS system blocks are given below.

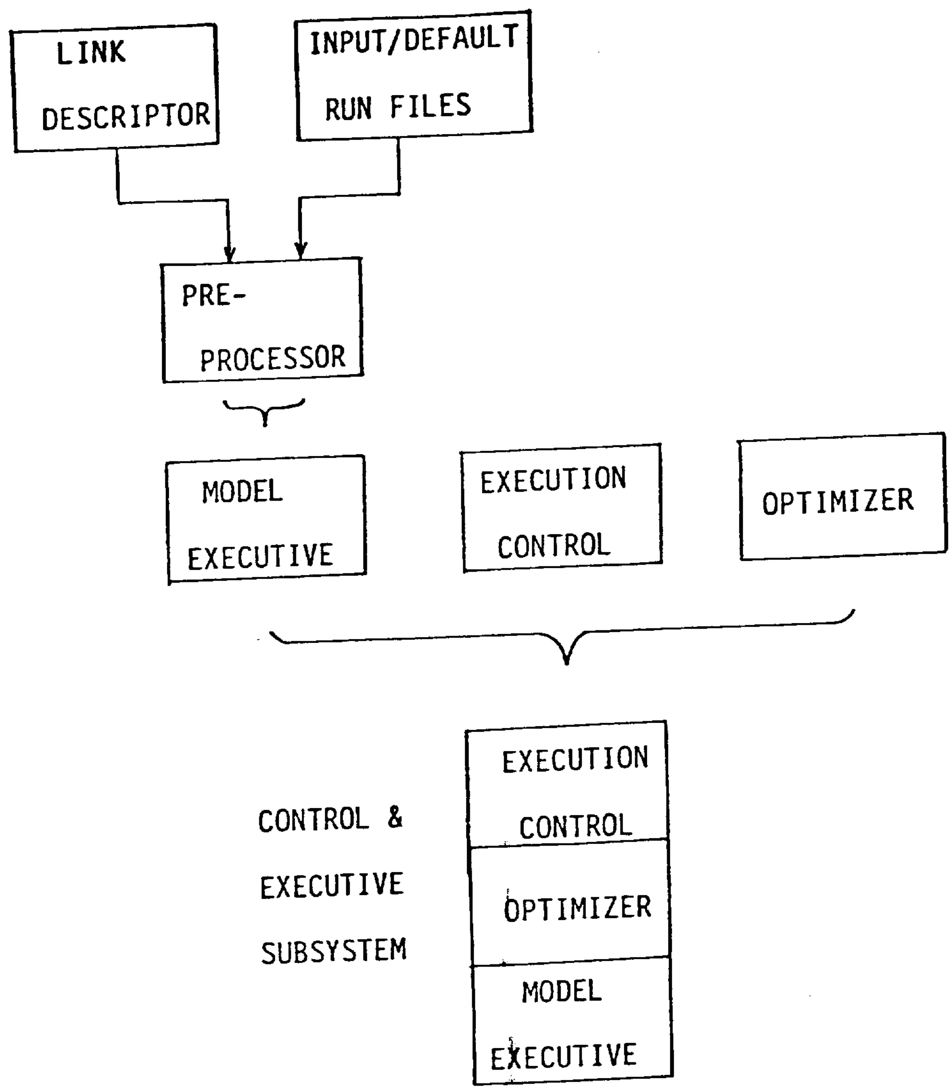

Figure 4.2 Procedure to Form the Control and Executive Subsystem.

4.2.1 Control Procedure

The SCSS control can be divided into two levels, a high level one and a low level one. The high level control performs the VAX/VMS operating system command level functions, while the low level control performs the detailed SCSS system execution control. The low level control is the function of the EC, and the high level control function belongs to the CP.

The CP governs the overall high level system flow of the SCSS. It also controls and links together all the SCSS building blocks. The following are some of the specific functions of the CP.

4.2.1.1 Program Linking

The SCSS Model Library consists of numerous C&T modeling modules. It is very inefficient (a waste of computer time and memory space) if all of the modules are linked together even though in the cases when most of them are not in use. A concept of adaptive program linking is required. Adaptive program linking essentially links only the necessary modules required to model and evaluate a particular C&T link specified. It is adaptive since it has the capability to select only the necessary modules required.

This capability is essential because during the software development and maintenance stages program updates and linking are frequent. Usually linking a large package may take more than an hour to complete. In addition, a large package requires too much computer memory and in turn may slow down the execution speed.

On the other hand, in some applications real time program linking may be preferably avoided completely. In case of no modification is required on a particular C&T link, the executable module will be saved so that it does not have to recreate and relink the modules.

4.2.1.2 Error Control

During the execution of SCSS, various VMS system level errors of different nature (e.g. arithmetic underflow and overflow, illegal addressing, illegal file access, etc.) may arise. In order to handle these errors without hampering the SCSS an error handling routine should be implemented. The error handling routine should allow various entry points of the SCSS according to the user's choice so that the operating system will not force the SCSS to be aborted. In addition, the error handling routine will avoid SCSS termination with unexpected results.

4.2.1.3 Interrupt Control

A user can interrupt the normal execution flow of the SCSS by tying a "Control Y". A user may like to do this if the current program state is not desirable and would like to discontinue the current state. Examples of this situation would be discontinuing the evaluation of a simulation of a C&T link due to prolonged execution, modification of the link, or selection of other simulation approach.

4.2.1.4 Security and Protection

SCSS security is designed to avoid information leakage, while SCSS protection is designed to avoid both intentional and unintentional system destruction. SCSS protection may not be necessary in the software development stage. However, it will become essential when it is in full operational stage, as a large number of users may be involved at this stage.

Users will be divided into four levels (1 to 4) of access privilege, with level 1 being the highest and 4 the lowest. Level 1 is assigned for the SCSS development, level 2 to SCSS system manager, level 3 to general users, and level 4 to nonprivileged users.

The level 1 users develop and upgrade the SCSS system software and thus have full access to all the software and files.

The level 2 user is the SCSS system manager (a single person) who is responsible for the general maintenance of all SCSS software and files (both system and personal). The system manager decides the privilege levels of a new user in order to protect the system, and also periodically changes the passwords.

The level 3 users are general users of the SCSS. They have the full privilege to access the SCSS capability but are only able to change their own personal files.

The level 4 users are nonprivileged users who are only given limited access of the SCSS. Any new users will be first given the level 4 privilege. They can be upgraded to level 3 when they are familiar with the SCSS operations. Users in this level can only run C&T link simulations without very heavy computation, so that they will not unnecssarily tie up the computer.

The privilege of each level is summarized in Table4.1.

4.2.1.5 SCSS Status

A SCSS status line is implemented at the bottom line of the screen to show the current status of the SCSS. It prints out a brief status message to show the current state (e.g. C&T link build up, simulation execution, file accessing, error, data output, linking, etc.) of SCSS so that a user may know what it is doing. It also helps to diagnose the SCSS in case any problem comes up. The status line also consists of a "CPU TIME" and an "ELAPSED TIME". The CPU TIME shows the CPU time used, and the ELAPSED TIME shows the time passed since the SCSS is invoked. These times indicate the overhead time for evaluating a certain C&T link performance.

4.2.1.6 Command Line

The command line contains the commands acceptable to the SCSS. At different stages of SCSS, the commands may be different. The "help" command may appear at all time so that a user may seek help from the system. Selection of commands within the command line may make use of the position control by the arrow keys in the keyboard.

Table 4.1 SCSS User Privilege Assignment

Privilege Level	Assignment	User Privilege
1	SCSS System Developer	Full access of SCSS capability and all files. Develop and modify the SCSS system.
2	SCSS System Manager	Full access of SCSS capability and all files. Maintain the SCSS system.
3	General Users	Full access of SCSS capability. Can only modify personal files.
4	Nonprivi-leged Users	Limited access of SCSS capability. Can only modify personal files.

4.2.1.7 Batch Processing

In case a simulation may take a long time to complete, batch processing may be desirable. Batch processing does not tie up a terminal, and thus will not be affected by any accidental disturbance of the terminal and connections. Batch processing may also make use of the computer resources when they are not busy, e.g. overnight execution. Output of batch jobs may be obtained from the Post-Processor after the job is over.

4.2.1.8 Parallel Processing

The VAX/VMS has the capability of spawning new child processes. Child process run concurrently with the parent process and is able to communicate with the parent process. Children processes can be spawned to do semi-independent processing in order to obtain higher computer throughput.

A user may also want to free the terminal to do something else while the simulation is in execution, and attach back to the simulation process at anytime.

Well organized usage of children processes may yield higher flexibility and throughput of the SCSS system.

4.2.2 Input/Output Subsystem

The Input/Output Subsystem performs the interface between the SCSS and the users. It consists of the Input/Output Processor and the Post-Processor. The IOS and the Modeling Subsystem can be run under a local microcomputer system (e.g. micro VAX 2) in the future. If such a processor existed, the main processor (VAX 11/750) could be released from doing heavy input/output operations, and higher throughput resulted.

4.2.2.1 Input/Output Processor

The Input/Output Processor is the interface between the SCSS and users. It converts the information into suitable forms so that the user and the SCSS system can understand and process. The Input/Output Processor may consist of several devices for different functions. It may be as simple as a CRT terminal, or as complicated as a microcomputer system.

4.2.2.1.1 Input Processor

The Input Processor unit converts the commands and parameters which a user would like to send to the SCSS. The simplest way is to do it through a color graphic CRT terminal. In order to make it efficient (speed and accuracy), the command inputs should be as simple and as short as possible. Special function keys such as arrows, help, return, space, and other system defined function keys should be used as much as possible. Field protection will be used to confine the input in the specified fields. Default values will be available, and input validity will be checked.

Future expansion of Input Processor could be a microcomputer system. It performs all the input/output functions locally instead of too much CPU interaction. Usually input is not a problem since the input data rate is low and the computer can handle it without too much delay. However, as discussed later, output speed could be more important.

4.2.2.1.1.1 Input Devices

The terminals used in SCSS may be of more than one model. The SCSS should possess the capability to handle several commonly used terminals. Future expansion of Input Device may involve a microcomputer such as a Micro VAX system.

4.2.2.1.1.2 Output Interface

Output format of the Input Processor will be ASCII sequences generated by CRT terminals. These characters (either printable or nonprintable will be read by other SCSS componenets.

4.2.2.1.2 Output Processor

The Output Processor unit displays the data and instructions output from the SCSS. They may be in the form of block diagrams, 2 or 3 dimensional graphics, or simply a line of data or SCSS instruction. Converting data into suitable format and displaying them may take some time. The speed of data conversion and display may be serious when a large number of data is available or when real time application is in process. In this respect, the major concerns of the Output Processor are output format flexibility and speed. Hard copy data will also be required.

A microcomputer system will be ideal to serve as an Output Processor controller. In the presence of this controller, all the data reduction function of the Post-Processor and display processing can be done locally without tying down the main processor. In other words, it yields higher speed in output processing.

When the SCSS is well developed and ready for real time applications, user interface by voice may be considered. Speech synthesizing technology is pretty well developed (e.g. Digital Equipment Corporation is marketing a speech synthesizer called Dectalk for about $3400.). It can be used to inform and alert an rations.

4.2.2.1.2.1 <u>Input Interface</u>

The input to the Output Processor will be formatted data ready to display by the output devices.

2.2.1.2.2 <u>Output Devices</u>

The output devices will be color graphic terminals, printers, color plotters, and possibly a speech synthesizer.

4.2.2.2 <u>Post-Processor</u>

The Post-Processor performs data reduction of the output data files and put it into suitable display formats. It then inputs it to the Input/Output Processor for final data processing and display. The output data files contain all the information of the C&T link signals and performance.

A user may want to display the information in any format preferred. For example, if a user wants to display the frequency spectrum of a signal while the output data file contains only the time domain sequence, then the Post-Processor will perform the required signal conversion from time to frequency domain. A user may also display any portion of the stored information in any scale and format. More than one graph can be displayed at the same time so that convenient comparison can be achieved.

4.2.2.2.1 Input Interface

The Post-Processor accepts data files from the Output Data Files. Since there will be many data files available as a result of the simulation, an output file descriptor (OFD, a file by itself) will be created to describe all the output files. The Post-Processor can retrieve information from the OFD regarding where the information is located.

4.2.2.2.2 Output Interface

Output of the Post-Processor to the Input/Output Processor will be data files to be displayed.

4.2.3 Modeling Subsystem

The Modeling Subsystem consists of the Link Descriptor and the Pre-Processor. They define the C&T link model to be evaluated by the SCSS. As discussed earlier, the MS will be ideally located in a local microcomputer.

4.2.3.1 Link Descriptor

The Link Descriptor defines the C&T link to be evaluated by the SCSS. The definition can either be made by building up the link block diagram or using existing input/default file. The output of the Link Descriptor will be input to the Pre-Processor for further processing.

4.2.3.1.1 C&T Link Construction

The easiest way to create a C&T link is perhaps accomplished by defining its link block diagram. The SCSS has the capability to guide a user to create a link graphically. A user can select the system blocks from the Model Library to make up the desired link. The options of addition and deletion of any block in the link will be provided so that any modification of existing link would be very simple.

The parameters associated with each system block will be defined after the whole link is set. The block whose parameters are to be defined will be highlighted with a different color in order to help identify the current block. Default values are given and all input values will be automatically checked by the system for validity.

4.2.3.1.2 Input/Default Run File

A run file is used to define the C&T link to be evaluated. It contains the necessary information of the link structure. Along with an associated parameter file a unique link can be defined. If an existing input run file is the desirable one, it can be directly input to the Pre-Processor without going through the detailed operations of the Link Descriptor. If a run file is to be modified, the easiest and safest way is to call up the run file through the Link Descriptor. Direct editing of a run file is possible. However, a user has to understand the data structure of the run file in order to maintain the interface compatibility.

4.2.3.1.3 Output Interface

The output interface of the Link Descriptor to the Pre-Processor is a run file and an associated parameter file containing all the information of a unique C&T link.

4.2.3.2 Pre-Processor

The Pre-Processor is the one to set up the appropriate link evaluation environment given the defined C&T link stored in the given run file. If a user calls up an old run file (no C&T link modification required), the Pre-Processor will first check whether all the associated files already exist (saved in the previous SCSS operations). If they exist, then the PRP will skip the following operations and pass the control to the Control & Executive Subsystem. Otherwise, the following operations will be started.

The PRP accepts a run file as an input and creates a Model Executive. The Model Executive will then be merged with the Execution Control and the Optimizer modules to form the executable Control & Executive module. The detailed functions of the PRP will depend on the link evaluation option (analysis, anlytical simulation, or simulation) chosen by a user.

If the option of analysis was chosen, the PRP will select an appropriate module from the Model Library and use it as the Model Executive module ModExec.OBJ. The file CES.COM containing a VMS LINK command will be created. Its content is typically

```
$ LINK /EXECUTABLE=CONTEXC ExCont, Optmz, UserDyn, ModExec
```

The Execution Control module (ExCont.OBJ) serves as the main program. The optimization module (Optmz.OBJ) and the user dynamics module (UserDyn.OBJ) will be actual modules or dummy modules (of much smaller sizes) depending on whether the C&T link optimization and user dynamics options are selected or not. After the command file CES.COM is executed, the executable module CONTEXC.EXE will be resulted to form the Control & Executive Subsystem. A parameter file PF.DAT will also be used to contain all the link parameters for link evaluation.

If the options of analytical simulation or simulation is chosen, the ModExec.C file is created. This file contains all the function (located in the Model Library) calls required for simulation. These calls will be arranged in a logical sequence in order to simulate the link in a logical and efficient manner. The ModExec.C will be compiled, and the CES.COM similar to the one above is created. However, its content will now typically be

```
$ LINK /EXECUTABLE=CONTEXC ExCont, Optmz, UserDyn, ModExec,
   F1, F2, .., Fn
```

Here, the modules F1.OBJ, F2.OBJ, ..., Fn.OBJ are function modules (located in the Model Library) to be called by the ModExec. It will also create the parameter file PF.DAT containing the simulation parameters. In addition, a signal file SIG.DAT will be created to contain the initial signal waveform to be processed. The length and format of the signal sequence are treated as parameters and are determined by the user.

The PRP operations is summarized in Fig. 4.3.

4.2.3.2.1 Input Interface

The inputs to the PRP are the run file and parameter file output from the Link Descriptor. Modules in the Model Library also serve as inputs in the linking stage.

4.2.3.2.2 Output Interface

The outputs of the PRP will be the CONTEXC.EXE and PF.DAT for the analysis option, and also the SIG.DAT for the other two simulation options.

Fig. 4.3 <u>The Pre-Processor Operations</u>

1. Receive the Run File from the Link Descriptor.
2. New Run File ?

   If no

   All required files (e.g. CONTEXC.EXE, PF.DAT, SIG.DAT) exist ?

   If yes, then go to (5).

   If no, continue (3).

   If yes, continue (3).
3. Analysis ?

   If no, go to (4).

   If yes, then do

   { Select the right module from the Model Library.

   Use it as the Model Executive ModExec.OBJ.

   Create CES.COM

   "$ LINK /EXECUTABLE=CONTEXC ExCont, Optmz, UserDyn, ModExec"

   Execute CES.COM to obtain CONTEXC.EXE.

   Create PF.DAT.

   }

   Go to (5).
4. Analytical simulation or simulation ?

   If no, error. Go back to check the option chosen.

   If yes, then do

   { Create ModExec.C (sequences of function calls).

Compile ModExec.C.

Create CES.COM.

"$ LINK /EXECUTABLE=CONTEXC ExCont, Optmz, UserDyn,

ModExec, F1, F2, ..., Fn"

Execute CES.COM to get CONTEXC.EXE.

Create PF.DAT.

Create SIG.DAT.

}

5. Pass control to the Control & Executive Subsystem.

4.2.4 Control & Executive Subsystem

The Control & Executive Subsystem is the central control and execution of the C&T link simulation part of the SCSS. Compared to the Control Procedure, the CES is a low level controller. It only controls the functions related to the link evaluation rather than the overall SCSS. Beside the controlling function, the CES also performs the link evaluation and optimization. During the SCSS execution, most of the computing time will be spent in this subsystem.

4.2.4.1 Execution Control

The Execution Control provides execution control to link evaluation as specified in the PRP. The EC is by itself the main program module of the Control & Executive Subsystem, which by itself is an executable module. The EC will serve as the controller of the C&T link evaluation and interface with the Control Procedure and the Dynamics Controller. It also supervises the optimizer module to perform the link evaluation optimization.

In the case that neither optimization nor user dynamics is present, the Model Executive will be called and output data is forwarded to the Output Data Files. This procedure can be repeated with new parameters according to the control data in the PF.DAT.

In the case that only optimization is required but not the user dynamics, the ME will go into an optimization procedure. The optimization procedure will be executed until the optimized performance under the specified constraints is found. The evaluation procedure can be repeated again with new parameters in the PF.DAT.

In the case that only user dynamics is required but not the optimization, the ME will go into a user dynamics loop. The ME will be called for every state of the user dynamics. Link performance is thus obtained for every state. The evaluation procedure can be repeated with new parameters.

The procedure, however, is somewhat different if both optimization and user dynamics are required at the same time. Here the meaning of optimization is not well defined. It may mean the optimal performance value for a certain state of user dynamics, or the optimal value over all user dynamics. For the first case, provided a user dynamic state, the procedure in getting the optimal value is the same as the normal case. For the second case, the dynamic ranges of the user dynamics have to be known first, then the optimization procedure starts to find the optimal value over the dynamic ranges along with other parameters. It seems that the first case is the one usually used. However, capability for handling both situations can be implemented.

Fig. 4.4 illustrates the operations of the Execution Control.

4.2.4.1.1 Input Interface

Input to the Execution Control are parameter file PF.DAT,

Fig. 4.4 The Execution Control Operations

```
/*  Begin CES operations                                          */
       read (OP_control_data) from PF.DAT
       read (DC_control_data) from PF.DAT
       if (optimal_only) then go to optimal:
       if (user_dynamics_only) then go to user_dynamics:
       if (optimal_for_each_user_dynamic_state)
          then go to optimal_dynamic_1:
       if (optimal_over_all_user_dynamic_states)
          then go to optimal_dynamic_2:
/*                                                                */
/*   Model Execution with neither active optimization nor        */
/*   user dynamics.                                               */
/*                                                                */
loop:
       read (exec_control_data) from PF.DAT
       call ME
       write (output_data) to ODF
       if (repeat)
         then go to loop:
         else go to over:
/*                                                                */
/*    Optimizer is in use only.                                   */
/*                                                                */
optimal:
```

```
        read (exec_control_data) from PF.DAT
        call OP (exec_control_data, ME)
        /* Optimization algorithms are defined in the */
        /* function OP.  All outputs from ME          */
        /* evaluations are forwarded to ODF.          */
        if (repeat)
          then go to optimal:
          else go to over:
/*                                                          */
/*    User dynamics is in use only.                         */
/*                                                          */
user_dynamics:
        read (exec_control_data) from PF.DAT

user_dynamics_loop:
        call DC (exec_cotrol_data) /* DC output passed back */
        if (no_more_user_dynamics)
          then go to dynamics_over:
          else { call ME       /* ME run along with DC data */
                 write (output_data) to ODF
                 go to user_dynamics_loop:
               }
dynamics_over:
        if (repeat)
          then go to user_dynamics:
          else go to over:
```

```
/*                                                          */
/*  Both optimization & user dynamics are in use.           */
/*  Assuming optimal value for each user dynamics state.    */
/*                                                          */
optimal_dynamic_1:
       read (exec_control_data) from PF.DAT
user_dyn_loop:
       call DC (exec_control_data)
       /* exec_control_data passed back. */
       if (no_more_user_dynamics)
         then go to dyn_over:
         else
           { call OP (exec_control_data, ME)
             /* user_dynamic_data passed to OP. */
             /* Output values written to ODF.   */
             go to user_dyn_loop:
           }
dyn_over:
      if (repeat) then go to optimal_dynamic_1:
                  else go to over:
/*                                                          */
/*    Both optimization & user dynamics are in use.         */
/*    Assuming optimal value over all user dynamics.        */
/*                                                          */
optimal_dynamic_2:
       read (exec_control_data) from PF.DAT
```

```
        get (all_user_dynamics_data)
            from DC(exec_control_data)
        call OP (exec_control_data, ME)
        /* All the user dynamics data passed to OP for       */
        /* evaluation.                                       */

        if (repeat) then go to optimal_dynamic_2:
                     else go to over:
/*                                                           */
/*      CES operations are over.                             */
/*                                                           */
over:
        close (files)
        end
```

data from the Optimizer, Model Executive, and Dynamics Controller.

4.2.4.1.2 Output Interface

Output of the Execution Control are control data to the Optimizer, Model Executive, and Dynamics Controller.

4.2.4.2 Optimizer

The optimizer performs numerical optimization of a specified function. The function could be the C&T link performance to be evaluated. Given the specified parameters and probably also their value ranges, the optimizer will try to find out the optimized function value in an efficient manner.

4.2.4.2.1 Input Interface

Inputs of the Optimizer are link performance data passed from the Execution Control.

4.2.4.2.2 Output Interface

Outputs of the Optimizer are parameter values to the Execution Control. The EC in turn will pass these data to the Model Executive for link performance evaluation.

4.2.4.3 Model Executive

The Model Executive performs the evaluation of the C&T link model. The parameter file PF.DAT contains all the parameters necessary to describe the link model. The ME will produce the Output Data Files as output.

If the analysis option is specified for the link evaluation, then a single output file will be output as a result of the whole link evaluation. If the analytical similation or Monte Carlo simulation options are specified, then an individual output file will be output for every "node" of the link model. A node of a link is defined as either the source, the sink, or any point connecting two link building blocks.

The ME will access the Data Base for any data required for link evaluation. Data Base access will be read only so that accidental data destruction of the Data Base can be avoided.

The ME evaluation will be arranged to make use of the external Array Processor unit.

In the future, real time SCSS operations will be required for real time missions support (e.g. shuttle, Free-Flyer, OMV missions). Design structure of the ME will be made to facilitate the real time operations.

4.2.4.3.1 Input Interface

Inputs to the Model Executive include the parameter file PF.DAT, signal file SIG.DAT, data from the Data Base, and data and control from the Execution Control.

4.2.4.3.2 Output Interface

Outputs of Model Executive are Output Data Files. They may be a single file for the case of analysis or a number of files in the case of analytical simulation or simulation.

4.2.5 Model & Data Subsystem

The Model and Data Subsystem is essentially a file storage for the SCSS. It stores all the system files in the Model Library and Data Base. It also holds the output files in the Output Data Files. In order to protect the files in the Model Library and Data Base, these files are kept in a separate account and are only readable by users in other accounts.

4.2.5.1 Model Library

The Model Library is a collection of modules modeling the C&T links. Each module either models an individual C&T building block or simply an end-to-end link. There are two kinds of files in the Model Library, the object files (XXX.OBJ) and executable files (XXX.EXE). The object files are modules to be linked with other modules to form an executable file. These files are used when analytical simulation or simulation options are used. The executable files are used for analytical option. Since for this case, no C&T link modification is necessary, an executable file ready for a link analysis will be kept in the Model Library.

Users can save any executable files for particular link simulations in their own directories if the files are frequently used. In that case, compilation and linking can be totally eliminated.

4.2.5.1.1 Input Interface

Selection of modules from the Model Library is controlled by the Control Procedure and the Pre-Processor with the specification given in the run file.

4.2.5.1.2 Output Interface

Output of Model Library will be modules either in the form of object files or executable files.

4.2.5.2 Data Base

The Data Base will hold all the data related to the C&T link evaluation. It will include the data such as environmental data (e.g. relative position of the Space Station with the earth, the shape of the Space Station and other spacecrafts, the positions of antennas etc.), RFI simulation data, atmospheric data (if necessary), fixed hardware parameters and others.

The Data Base should be designed for fast data access and efficient disk storage. File types like contiguous, linked, indexed, and fixed and variable record length etc. could be considered in designing a file structure.

The Data Base in fact consists of many smaller data bases which individually is a collection of data in the same nature. The data structure of a data base is highly dependent on the nature of the data and their relationships. The concept of the hierarchical, network, and relational data base could be used in the data base design.

4.2.5.2.1 Input Interface

The Data Base will be used by the Model Executive during the execution of the link evaluation. Input of Data Base will be commands from the Model Executive.

4.2.5.2.2 <u>Output Interface</u>

Output of the Data Base will be the Model Executive.

4.2.5.3 <u>Output Data Files</u>

The Output Data Files is a storage for the output files of the Model Executive. The output files will be named according to the convention Nxxx.DAT, where xxx is the node number in the C&T link to be simulated. All the information concerning the files in the Output Data Files will be contained in the output file descriptor, OFD. The Post-Processor can later on go to the OFD for files information and perform further processing.

4.2.5.3.1 <u>Input Interface</u>

The files are created by the Model Executive during the link evalutation.

4.2.5.3.2 <u>Output Interface</u>

The files will be processed by the Post-Processor.

4.2.6 User Dynamics Subsystem

The User Dynamics Subsystem generates simulation data of the user dynamics and inputs them to the Execution Control for simulation. The simulation data can either be generated offline or in real time. In the first case, data are input as a file. In the second case, real time interface capability has to exist in handling the real time input data.

4.2.6.1 Orbit Generator

The Orbit Generator will generate the spacecraft orbit trajectories for both the Space Station and the users. These orbit trajectories contain all the information on the user dynamics parameters such as range, range rate, and look angles. Along with the data in the Data Base, the antenna blockage and signal multipath due to the spacecraft bodies can also be generated.

The data can either be generated offline or real time.

4.2.6.1.1 Input Interface

The orbit trajectories can be generated by simulations under program control. It can also be input by a user in the form of a data file or a single data. Real time or nonreal time inputs are acceptable.

4.2.6.1.2 Output Interface

The outputs of the Orbit Generator will be forwarded to the

Dynamics Controller for further processing.

4.2.6.2 Dynamics Controller

The Dynamics Controller will extract the user dynamics parameters from the orbit trajectories generated by the Orbit Generator. These parameters can be used by the Control and Executive Subsystem as part of the information to simulate the C&T link performance. Interfaces with the Execution Control has to exist in order to handle both real time and nonreal time data.

4.2.6.2.1 Input Interface

The Dynamics Controller accepts orbit trajectories data from the Orbit Generator either real time or nonreal time.

4.2.6.2.2 Output Interface

The Dynamics Controller outputs user dynamics parameters to the Execution Control either real time or nonreal time.

4.2.7 Array Processor

The Array Processor serves as a device to speed up the computation of the numerical evaluation. The array processor has a number of specific subroutines to be called to perform the numerical computation. In order to make use of these subroutines, the input and output data formats have to be arranged in the forms compatible to the requirements. Since overhead exists in data input/output and format transformations in using the array processor, minor computation will not make use of it and will be simply done in the main computer.

4.2.7.1 Input Interfae

The data input to the Array Processor will be passed from the Model Executive in compatible formats of the subroutine calls.

4.2.7.2 Output Interface

The data output from the Array Processor will go back to the Model Executive for further processing.

REFERENCES

[1] M. C. Jeruchim, "Techniques for Estimating the Bit Error Rate in the Simulation of Digital Communication Systems", IEEE Journal on Selected Areas in Communications, Jan. 1984.

[2] W. R. Braun and T. M. McKenzie, "CLASS: A Comprehensive Satellite Link Simulation Package", IEEE Journal on Selected Areas in Communications, Jan. 1984.

[3] R. W. Lucky, J. Salz, and J. Weldon, Principles of Data Communication, McGraw-Hill, New York, 1968.

[4] P. Hetrakul and D. P. Taylor, "The Effects of Transponder Nonlinearity on Binary CPSK Signal Transmission", IEEE Transactions on Communications, May 1976.

[5] J. J. Spilker, Digital Communications by Satellite, New Jersey, Prentice-Hall, Inc., 1977.